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III
Vol. 5

# INTERPRETATION, COMPILATION AND FIELD VERIFICATION PROCEDURES IN THE CARETS PROJECT

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By
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U.S. Geological Survey

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## FINAL REPORT—VOLUME 5

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Goddard Space Flight Center
Greenbelt, Maryland 20771
and
U.S. Geological Survey
Reston, Virginia 22092
1975

# INTERPRETATION, COMPILATION, AND FIELD VERIFICATION PROCEDURES IN THE CARETS PROJECT

By Robert H. Alexander, Peter W. DeForth, Katherine A. Fitzpatrick, Harry F. Lins, Jr., Herbert K. McGinty, III

U.S. Geological Survey
Reston, Virginia





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**16. Abstract**


The production of the CARETS map data base involved the development of a series of procedures for interpreting, compiling, and verifying data obtained from remote sensor sources. Level II land use mapping from high-altitude aircraft photography at a scale of 1:100,000 required production of a photomosaic mapping base for each of the 48, 50 x 50 km sheets, and the interpretation and coding of land use polygons on drafting film overlays. CARETS researchers also produced a series of 1970 to 1972 land use change overlays, using the 1970 land use maps and 1972 high-altitude aircraft photography. To enhance the value of the land use sheets, researchers compiled series of overlays showing cultural features, county boundaries and census tracts, surface geology, and drainage basins.

In producing Level I land use maps from Landsat imagery, at a scale of 1:250,000, interpreters overlaid drafting film directly on Landsat color composite transparencies and interpreted on the film. They found that such interpretation involves pattern and spectral signature recognition. In studies using Landsat imagery, interpreters identified numerous areas of change but also identified extensive areas of "false change," where Landsat spectral signatures but not land use had changed.


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CARETS/LANDSAT INVESTIGATION SR-125 (IN-002)

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Volume 1. CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE: A PROTOTYPE REGIONAL ENVIRONMENTAL INFORMATION SYSTEM by Robert H. Alexander

2. NORFOLK AND ENVIRONS: A LAND USE PERSPECTIVE by Robert H. Alexander, Peter J. Buzzanell, Katherine A. Fitzpatrick, Harry F. Lins, Jr., and Herbert K. McGinty III

3. TOWARD A NATIONAL LAND USE INFORMATION SYSTEM by Edward A. Ackerman and Robert H. Alexander

4. GEOGRAPHIC INFORMATION SYSTEM DEVELOPMENTS ASSOCIATED WITH THE CARETS PROJECT by Robin G. Fegeas, Katherine A. Fitzpatrick, Cheryl A. Hallam, and William B. Mitchell

5. INTERPRETATION, COMPILATION AND FIELD VERIFICATION PROCEDURES IN THE CARETS PROJECT by Robert H. Alexander, Peter W. DeForth, Katherine A. Fitzpatrick, Harry F. Lins, Jr., and Herbert K. McGinty III

6. COST-ACCURACY-CONSISTENCY COMPARISONS OF LAND USE MAPS MADE FROM HIGH-ALTITUDE AIRCRAFT PHOTOGRAPHY AND ERTS IMAGERY By Katherine A. Fitzpatrick

7. LAND USE INFORMATION AND AIR QUALITY PLANNING: AN EXAMPLE OF ENVIRONMENTAL ANALYSIS USING A PILOT NATIONAL LAND USE INFORMATION SYSTEM by Wallace E. Reed and John E. Lewis

8. REMOTELY-SENSED LAND USE INFORMATION APPLIED TO IMPROVED ESTIMATES OF STREAMFLOW CHARACTERISTICS by Edward J. Pluhowski

9. SHORE ZONE LAND USE AND LAND COVER: CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE by R. Dolan, B. P. Hayden, C. L. Vincent

10. ENVIRONMENTAL PROBLEMS IN THE COASTAL AND WETLANDS ECOSYSTEMS OF VIRGINIA BEACH, VIRGINIA by Peter J. Buzzanell and Herbert K. McGinty III

11. POTENTIAL USEFULNESS OF CARETS DATA FOR ENVIRONMENTAL IMPACT ASSESSMENT by Peter J. Buzzanell

12. USER EVALUATION OF EXPERIMENTAL LAND USE MAPS AND RELATED PRODUCTS FROM THE CENTRAL ATLANTIC TEST SITE by Herbert K. McGinty III

13. UTILITY OF CARETS PRODUCTS TO LOCAL PLANNERS: AN EVALUATION by Stuart W. Bendelow and Franklin F. Goodyear (Metropolitan Washington Council of Governments)

c

Contents


Abstract------------------------------------------------------------ 1
Introduction-------------------------------------------------------- 3
High-altitude aircraft mission planning and coordination---------- 4
Preparation of photomosaics---------------------------------------- 20
Development of the land use classification scheme---------------- 25
Interpretation and mapping for 1970 land use data from high-altitude aircraft photography------------------------------------------ 36
Photointerpretation key for use with high-altitude photography in CARETS-------------------------------------------------------------- 39
Field verification of land use information------------------------ 46
  Field checking in southeastern Virginia------------------------- 46
  Field checking the remainder of the CARETS region-------------- 57
  Accuracy investigations from helicopter------------------------ 57
  Systematic sampling for accuracy------------------------------- 62
High-altitude aircraft photography change detection-------------- 64
Compilation of other overlays------------------------------------- 67
Land use mapping using Landsat imagery---------------------------- 75
Change detection procedures using Landsat imagery---------------- 84
Comparison of Landsat and aircraft data for land use mapping------ 110
Recommendations---------------------------------------------------- 113
References--------------------------------------------------------- 117

Illustrations


Figure 1. Central Atlantic Regional Ecological Test Site: Index to ERTS 1 coverage---------------------------------- 7
2. Central Atlantic Regional Ecological Test Site: Photographic index, NASA aircraft mission 144 September 1970- 10
3. Central Atlantic Regional Ecological Test Site: Photographic index, NASA aircraft mission 145 October 1970 -- 11
4. Central Atlantic Regional Ecological Test Site: Photographic index, NASA aircraft mission 166 May 1971------- 12
5. Central Atlantic Regional Ecological Test Site: Photographic index, Earth Resources aircraft project (ERAP) flight 72-147, August 22, 1972------------------------- 13
6. Central Atlantic Regional Ecological Test Site: Photographic index, ERAP flight 72-208, December 2, 1972----- 14
7. Central Atlantic Regional Ecological Test Site: Photographic index, ERAP flight 72-209, December 3, 1972----- 15
8. Central Atlantic Regional Ecological Test Site: Photo--graphic index, ERAP flight 73-010, January 26, 1973----- 16
9. Central Atlantic Regional Ecological Test Site: Photographic index ERAP, flight 73-014C, January 31, 1973---- 17
10. Central Atlantic Regional Ecological Test Site: Photographic index, ERAP flight 73-181, October 27, 1973----- 18
11. Central Atlantic Regional Ecological Test Site: Photographic index ERAP, flight 73-185, November 1, 1973----- 19
12. Central Atlantic Regional Ecological Test Site: Index to 48 sheets for CARETS 1:100,000 scale data base------- 21
13. Controlled photomosaic, 1970, of the Washington Sheet, D.C., MD., VA.------------------------------------------ 22
14. Central Atlantic Regional Ecological Test Site: Areas of CARETS not covered by 1970 high-altitude aircraft photography------------------------------------------------- 23
15. Land use map in 1970 of the Washington sheet, D.C., MD., VA.----------------------------------------------- 38
16. CARETS photomorphic regions----------------------------- 61
17. Land use change map, 1970-72, Washington sheet, D.C., MD. VA.--------------------------------------------------- 66
18. Cultural features map, 1970, Washington sheet, D.C., MD., VA.--------------------------------------------------- 68
19. County boundary and census tract map, 1970, Washington sheet, D.C., MD., VA.---------------------------------- 69
20. Drainage basin map, 1970, Washington sheet, D.C., MD., VA.--------------------------------------------------- 70
21. Landforms and surface materials map, Washington sheet D.C., MD., VA.------------------------------------------ 71
22. ERTS land use, 1972------------------------------------ 76
23. Central Atlantic Regional Ecological Test Site: Index to 8 sheets for CARETS 1:250,000 scale data base-------- 78

Figure 24. Central Atlantic Regional Ecological Test Site: Location of 5 x 5 km sample sites within nonurban areas--- 89

25. Central Atlantic Regional Ecological Test Site: Urbanized Areas. Location of 2 x 2 km sample sites within urbanized areas. Shaded areas represent urbanized areas defined by the U.S. Bureau of Census, Census of Population: 1970 Vol. 1 & 2.------------------------------------------ 90

26. Land use change from agriculture (2) to urban (1) identified n the Coatsville sample site using ERTS imagery. EDC-010114.------------------------------------------ 95

27. Land use change from forest (4) to agriculture (2) identified in the Elkton sample site using ERTS imagery------ 97

28. Land use change from agriculture (2) to forest (4) identified on the Rehoboth sample site using ERTS imagery-99

29. Land use change from agriculture (2) to forest (4) identified in the Washington sample site using ERTS imagery-- 101

30. Land use corrections from urban to agriculture the Richmond sample site, mapped as a change from 1970-72---- 105

31. Land use boundary change from 1970-1972, at the Atlantic City sample site, marked as a change from forest (4) to wetland (6).------------------------------------------ 107

Tables


Table 1. Key to index to ERTS-1 coverage---------------------- 8
2. Scheme I: A tentative classification scheme for use with orbital imagery and with some supplementary information for making land use maps for the United States ranging in scale from 1:250,000 to 1:2,500,000--------- 26
3. Scheme II: A tentative classification scheme for use with orbital imagery but with little or not supplementary information for making land use maps ranging in scale from 1:250,000-------------------------------------- 29
4. Census cities land use classification---------------- 30
5. U.S. Geological Survey land use classification system for use with remote sensor data----------------------- 32
6. Land use categories in the Central Atlantic Regional Ecological test site data base----------------------- 34
7. U.S. Geological Survey land use and land cover classification system for use with remote sensor data-------- 35
8. Percentage of actual use occupying mapped land use categories---------------------------------------- 52
9. Percentage of actual land use occupying land use boundary areas------------------------------------------------ 53
10. Field editing worksheet------------------------------- 58
11. Percentage of correct land use interpretation of problem areas------------------------------------------------ 59
12. Landforms and surface materials classification legend-- 74
13. Image signatures, by land use category for Landsat visible and near infrared black-and-white imagery------- 83

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CARETS investigators conducted extensive field verification exercises to determine and improve map accuracy. They also used field checking to test the USGS land use classification scheme.

From the CARETS interpretation and compilation experience, investigators conclude that the high-altitude aircraft photography is easier to interpret and provides greater detail and more accurate data than does Landsat imagery. Landsat imagery, on the other hand, allows interpreters to produce a very generalized land use map of a large area, quickly and inexpensively.

# INTRODUCTION

The Central Atlantic Regional Ecological Test Site (CARETS) project has been an experimental multiagency, multidisciplinary research effort to test the value of remote sensor-derived land use data as input to a regional land resource information system. It has been sponsored jointly by the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey (USGS), two agencies interested in the application of remote sensor technology to the solution of environmental problems. The CARETS region covers a 74,712 $km^2$ area of the basins of the Chesapeake and Delaware Bays. The region's 1970 population of 13,404,588 is highly concentrated along the urbanized northeast corridor, consisting of the cities of Philadelphia, Wilmington, Baltimore, Washington, D.C., Richmond, and Norfolk.

The CARETS investigation has been organized into four closely related and integrated experiment modules:

(1) land use information module--acquiring and testing land resource data;

(2) environmental impact applications module--sponsoring research into the applications of land resource data for use in environmental impact studies;

(3) user interaction and evaluation module--promoting interaction between project investigators and potential users of the CARETS data and obtaining user evaluation of CARETS data products; and

(4) geographic information systems module--digital processing of land use data to enhance their value.

This report concerns the portion of the land use information module involved with preparing land use data products from high-altitude aircraft photography and Landsat imagery and presents recommendations on how the procedures used in the CARETS project can be improved.

## HIGH-ALTITUDE AIRCRAFT MISSION PLANNING AND COORDINATION

The initial CARETS land use mapping effort required source photography providing greater detail than Landsat imagery and also suitable for constructing geometrically rectified gridded mapping bases. The photographic data used in the production of the land use data base was acquired by a NASA RB-57 aircraft, which flew three missions--missions 144 and 145 in 1970 and 166 in 1971, in support of the CARETS project.

The planning and coordination of the NASA aircraft missions was conducted in two steps. The first required the investigator to design a flight over his test site, including specifications of altitude, sensors, film/filter combinations, area of coverage, cloud cover requirements, time of year, time of day, and amount of overlap. The second step required the submission of this mission plan to NASA for consideration and inclusion into its aircraft scheduling operation. For missions 144, 145 and 166, CARETS investigators coordinated the flight planning between USGS and NASA's Johnson Spaceflight Center (JSC) in Houston. Aircraft flights were then handled through JSC under the Earth Resources Aircraft Program.

In 1971 NASA acquired two U-2 aircraft and transferred control of flight operations to Ames Research Center at Moffett Field, California, under the title Earth Resources Aircraft Project. The primary function of the U-2 flights was to provide investigators with auxiliary high resolution color infrared photography at a scale of approximately 1:120,000. Mission planning and coordination for U-2 operations was handled like those for the RB-57.

The RB-57 aircraft was flown at an altitude of 60,000 feet (18,288 m). The sensor packages carried aboard were two Wild-Heerbrugg RC-8 Universal Aviogon metric cameras, one Zeiss RMK A 30/23 metric camera, and a cluster of six Hasselblad 500 EL cameras. The RC-8 camera has a 6-inch focal length lens and uses film 9 1/2 inches wide. The scale of RC-8 photography flown at 60,000 feet is 1:120,000. Most missions used one RC-8 camera loaded with color film and the other loaded with color infrared film. The Zeiss has a 12-inch focal length lens and usually was loaded with color infrared film. It produces a 9 x 9-inch negative at a scale of 1:60,000 when flown at an altitude of 60,000 feet. The Hasselblad cameras have 80 mm focal length lenses and have an image format of approximately 70 mm x 70 mm. This multiband cluster usually carried four black and white films, one each sensitive to the blue, green, red, and near infrared regions of the spectrum. The two remaining Hasselblads typically held color and color infrared film. Flown at an altitude of 60,000 feet, Hasselblad photography has a scale of approximately 1:450,000.

One can identify some features as small as 5 m in length from the RC-8 transparencies, 3-5 m from the Zeiss transparencies, and 14 m from Hasselblad transparencies. The RC-8 color infrared transparencies also provided relatively sharp detail, freedom from haze, and good color balance. Cloud cover problems affected only a small portion of the total area.

In comparison, the U-2 carried one Wild-Heerbrugg RC-10 metric camera and sometimes two and four Vinten System B cameras. The Vinten is a multiband cluster sensing in the green, red, and two near infrared bands corresponding to the wavelengths sensed by the Multispectral Scanner Subsystem (MSS) aboard Landsat. Data received from the U-2 flights were not only used as high-resolution underflight coverage for the Landsat

and Skylab investigations, but also as the update photography for producing the CARETS 1970-72 land use change maps. Figure 1 and table 1 present an index to Landsat coverage of the CARETS region. Figures 2 through 11 are indexes to photography obtained by the RB-57 and U-2 aircraft over CARETS in which the dots represent locations of selected photo frame centers along the flight lines. To minimize symbol crowding on these index maps, only frame numbers at ends of flight lines are shown. Locations of intervening frames may be estimated by interpolation. Copies of all NASA aircraft photography and Landsat imagery indexed may be purchased from the EROS Data Center, Sioux Falls, South Dakota 57198.

During the course of this investigation of the name of the Earth Resources Technology Satellite (ERTS) was changed to "Landsat." The term "ERTS", which appears in some of the material in this report is thus equivalent to the term "Landsat."

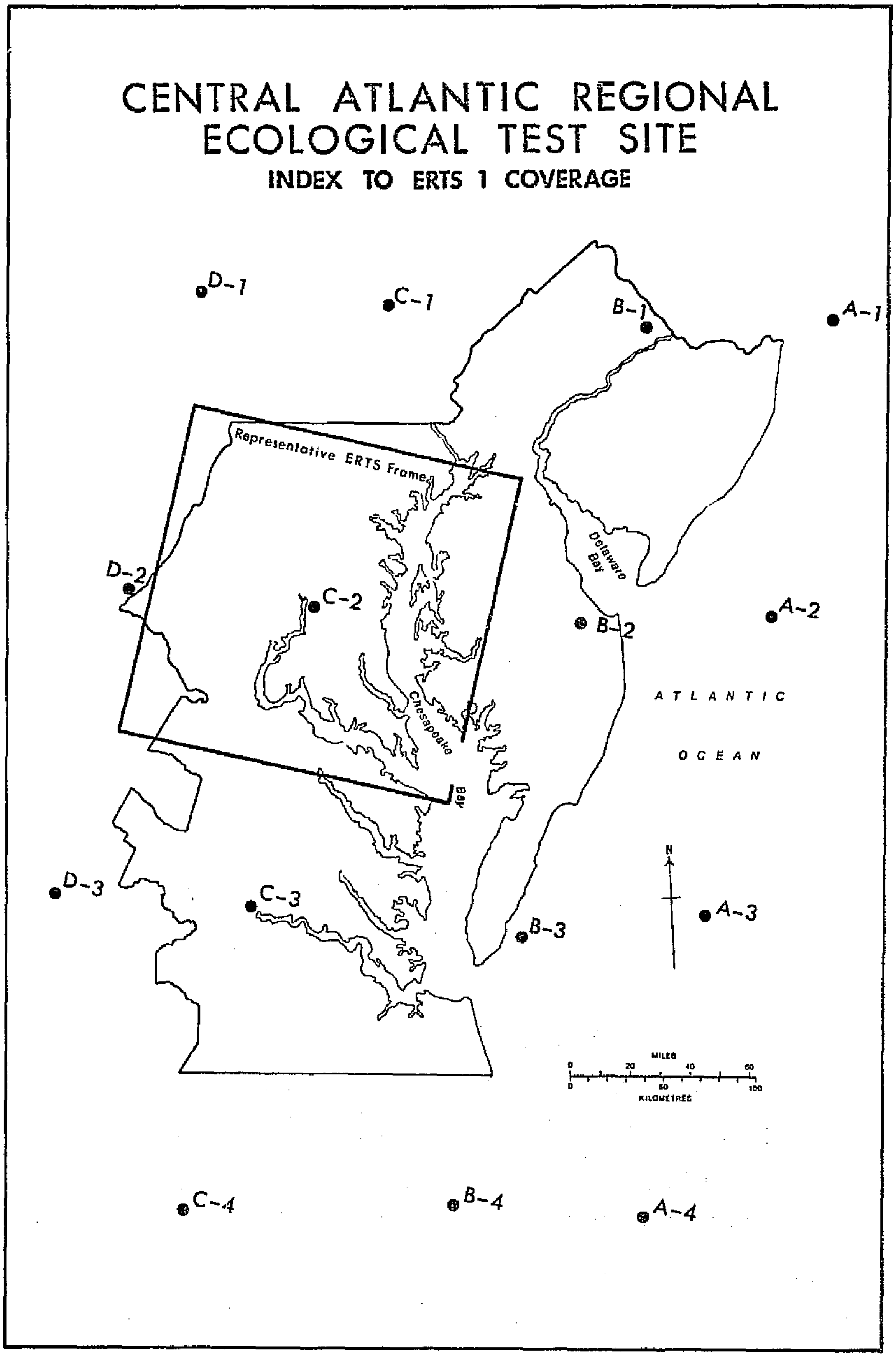


Figure 1.
see table 1 for key to index

Table 1.--Key to index to ERTS-1 coverage

**A-1**

09 Oct 72/1078-15072
07 Apr 73/1258-15085
13 May 73/1294-15081
13 May 73/1294-15083
06 Jul 73/1348-15073
16 Sep 73/1420-15060
04 Oct 73/1438-15060
22 Oct 73/1456-15052
20 Apr 74/1636-15020
08 May 74/1654-15013

**A-2**

09 Oct 72/1078-15075
07 Apr 73/1258-15082
31 May 73/1311-15002
06 Jul 73/1348-15080
29 Aug 73/1402-15071
16 Sep 73/1420-15062
22 Oct 73/1456-15055
08 May 74/1654-15015
04 Nov 74/1834-14561

**A-3**

09 Oct 72/1078-15081
02 Dec 72/1132-15085
03 Mar 73/1222-15091
06 Jul 73/1348-15082
29 Aug 73/1402-15074
16 Sep 73/1420-15065
04 Oct 73/1438-15065
15 Mar 74/1600-15033
04 Nov 74/1834-14563

**B-1**

10 Oct 72/1079-15131
03 Dec 72/1133-15135
26 Jan 73/1187-15133
03 Feb 73/1205-15135
01 Jun 73/1313-15141
07 Jul 73/1349-15132
30 Aug 73/1403-15123
23 Oct 73/1457-15111
10 Nov 73/1475-15110
26 Feb 74/1583-15091
03 Apr 74/1619-15080
21 Apr 74/1637-15074
23 Nov 74/1853-15011
11 Dec 74/1871-15000
03 Feb 75/1925-14574
21 Feb 75/1943-14570

**B-2**

10 Oct 72/1079-15133
03 Dec 72/1133-15141
26 Jan 73/1187-15140
03 Feb 73/1205-15141
01 Jun 73/1313-15134
07 Jul 73/1349-15134
12 Aug 73/1385-15131
30 Aug 73/1403-15125
26 Feb 74/1583-15084
03 Apr 74/1619-15083
21 Apr 74/1637-15080
23 Nov 74/1853-15013
11 Dec 74/1871-15002
21 Feb 75/1943-14572

**C-1**

11 Oct 72/1080-15185
16 Nov 72/1116-15192
09 Jan 73/1170-15191
09 Apr 73/1260-15195
08 Jul 73/1350-15190
31 Aug 73/1404-15181
31 Aug 73/1404-15184
06 Oct 73/1440-15172
09 Feb 74/1566-15144
27 Feb 74/1584-15143
22 Feb 75/1944-15024
17 Apr 75/1998-14594

**C-2**

23 Sep 72/1062-15190
11 Oct 72/1080-15192
09 Jan 73/1170-15193
09 Apr 73/1260-15201
02 Jun 73/1314-15195
08 Jul 73/1350-15192
13 Aug 73/1386-15190
06 Oct 73/1440-15175
11 Nov 73/1476-15171
22 Jan 74/1548-15163
09 Feb 74/1566-15153
27 Feb 74/1584-15145
24 Nov 74/1854-15065
22 Feb 75/1944-15033

**D-1**

06 Sep 72/1045-25243
10 Jan 73/1171-15245
23 Mar 73/1243-15253
16 May 73/1297-15252
25 Oct 73/1459-15223
30 Nov 73/1495-15222
18 Dec 73/1513-15220
18 Mar 74/1803-15195
11 May 74/1657-15184

**D-2**

06 Sep 72/1045-15245
10 Jan 73/1171-15252
23 Mar 73/1243-15260
16 May 73/1297-15254
01 Sep 73/1405-15242
19 Sep 73/1423-15240
25 Oct 73/1459-15230
30 Nov 73/1495-15225
18 Dec 73/1513-15214
10 Feb 74/1567-15205
18 Mar 74/1803-15202
31 Mar 75/1981-15071

Table 1.--Key to index to ERTS-1 coverage--continued

A-4

02 Dec 72/1132-15092
29 Aug 73/1402-15080
04 Oct 73/1438-15071
27 Nov 73/1492-15063
15 Mar 74/1600-15040
04 Nov 74/1834-14570

B-3

10 Oct 72/1079-15140
03 Dec 72/1133-15144
26 Jan 73/1187-15142
03 Feb 73/1205-15144
07 Jul 73/1349-15141
12 Aug 73/1385-15134
30 Aug 73/1403-15132
03 Apr 74/1619-15085
21 Apr 74/1637-15083
12 Sep 74/1781-15034
23 Nov 74/1853-15020
11 Dec 74/1871-15005
21 Feb 75/1943-14575

B-4

10 Oct 72/1079-15142
03 Dec 73/1133-15150
26 Jan 73/1187-15145
03 Feb 73/1205-15150
30 Aug 73/1403-15134
05 Oct 73/1439-15125
10 Nov 73/1475-15122
21 Apr 74/1637-15085
12 Sep 74/1781-15041

C-3

23 Sep 72/1062-15193
11 Oct 72/1080-15194
04 Dec 72/1134-15202
09 Jan 73/1170-15200
02 Jun 73/1314-15201
08 Jul 73/1350-15195
13 Aug 73/1386-15192
06 Oct 73/1440-15181
11 Nov 73/1476-15174
29 Nov 73/1494-15173
09 Feb 74/1566-15151
27 Feb 74/1584-15152
28 May 74/1654-15131
01 Oct 74/1800-15083
24 Nov 74/1854-15071
22 Feb 75/1944-15035

C-4

11 Oct 72/1080-15201
04 Dec 72/1134-15204
09 Jan 73/1170-15202
02 Jun 73/1314-15204
13 Aug 73/1386-15195
06 Oct 73/1440-15184
11 Nov 73/1476-15180
29 Nov 73/1494-15175
27 Feb 74/1584-15154
28 May 74/1674-15134
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22 Feb 75/1944-15038
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D-3

06 Sep 72/1045-15252
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23 Mar 73/1243-15262
16 May 73/1297-15161
09 Jul 73/1351-15253
19 Sep 73/1423-15242
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30 Nov 73/1495-15231
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28 Feb 74/1585-15213
23 Apr 74/1639-15200
31 Mar 75/1981-15073
06 May 75/5017-15053

D-4

23 Mar 73/1243-15265
16 May 73/1297-15263
03 Jun 73/1315-15262
25 Oct 73/1459-15235
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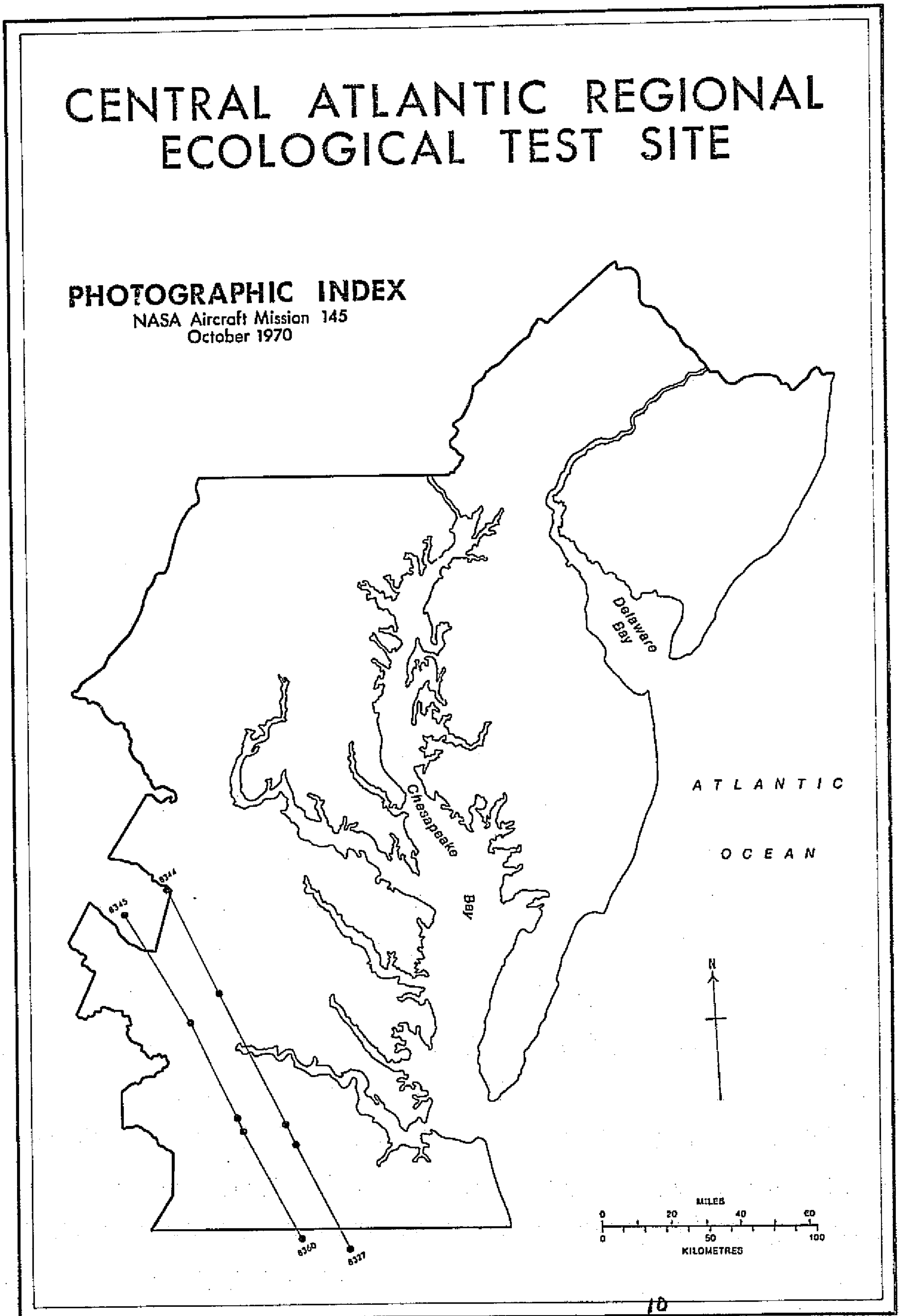

CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHOTOGRAPHIC INDEX
NASA Aircraft Mission 145
October 1970
Delaware Bay
Chesapeake Bay
ATLANTIC
OCEAN
N
MILES
0
20
40
60
0
50
100
KILOMETRES

Figure 3.

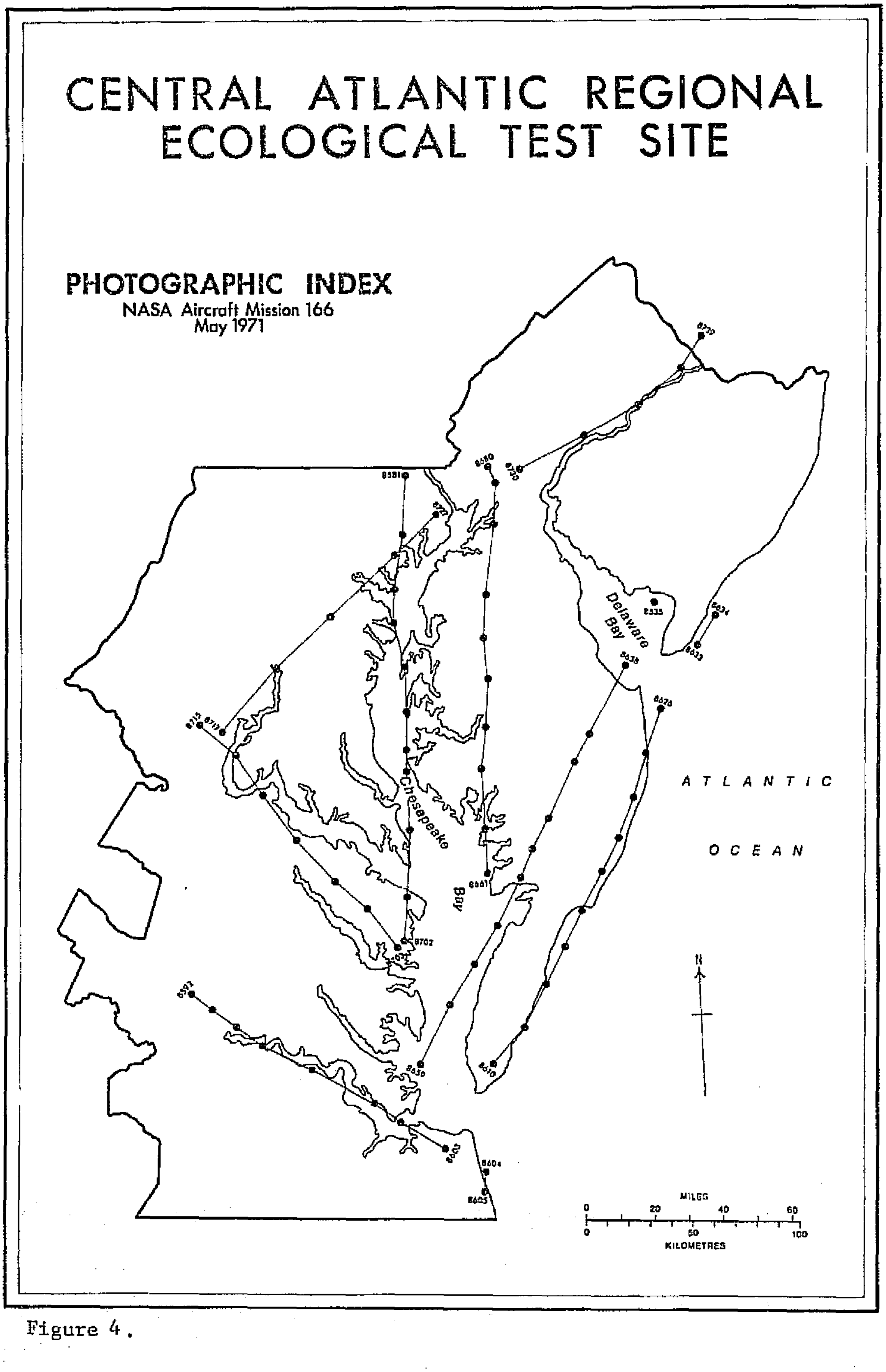
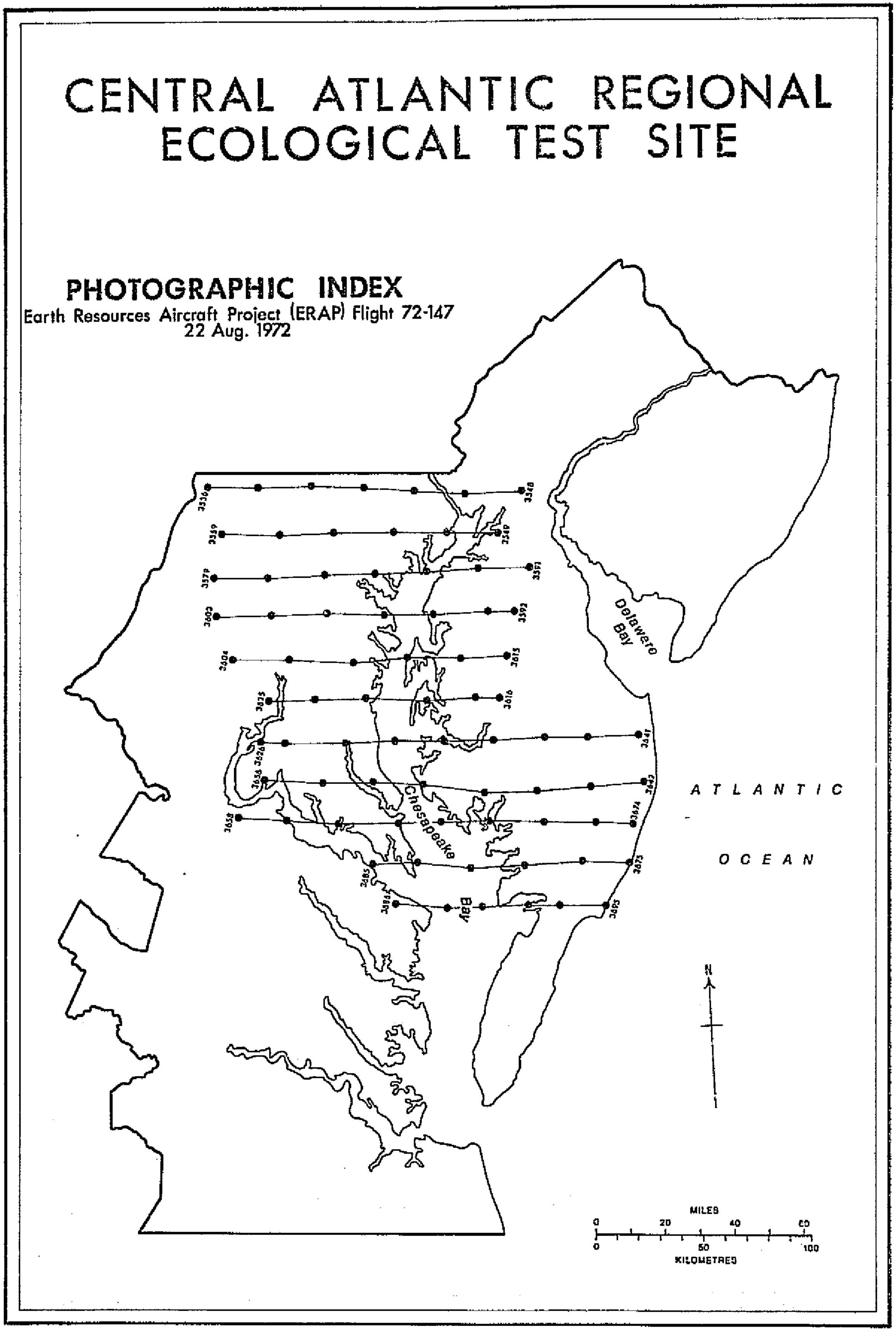

CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHOTOGRAPHIC INDEX
NASA Aircraft Mission 166
May 1971
Delaware Bay
Chesapeake Bay
ATLANTIC
OCEAN
N
MILES
0 20 40 60
0 50 100
KILOMETRES

Figure 4.


CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHOTOGRAPHIC INDEX
Earth Resources Aircraft Project (ERAP) Flight 72-147
22 Aug. 1972
Delaware
Bay
Chesapeake
Bay
ATLANTIC
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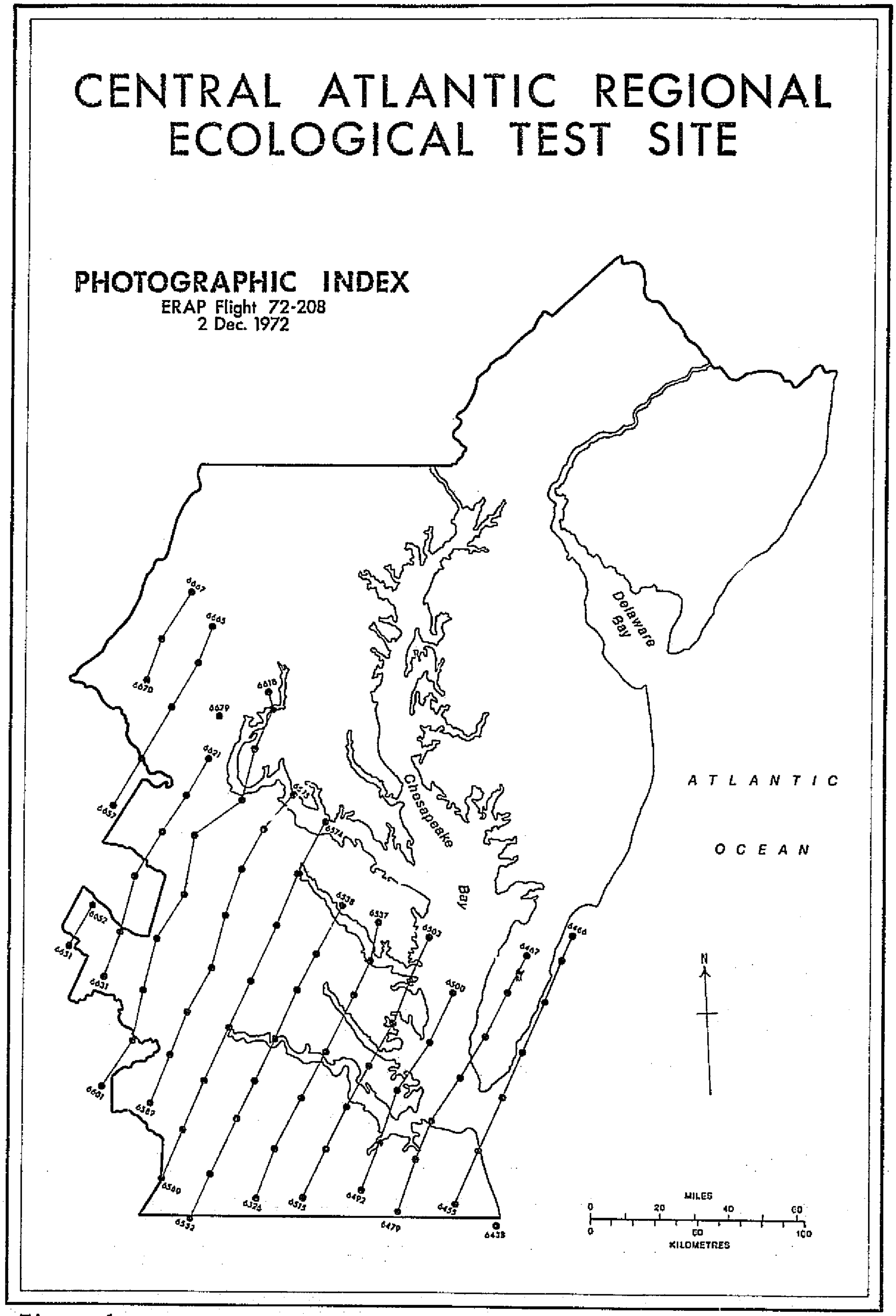
20
40
60
50
100
KILOMETRES

Figure 5.


CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHOTOGRAPHIC INDEX
ERAP Flight 72-208
2 Dec. 1972
Delaware Bay
Chesapeake Bay
ATLANTIC OCEAN
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MILES
0 20 40 60
0 50 100
KILOMETRES

Figure 6.

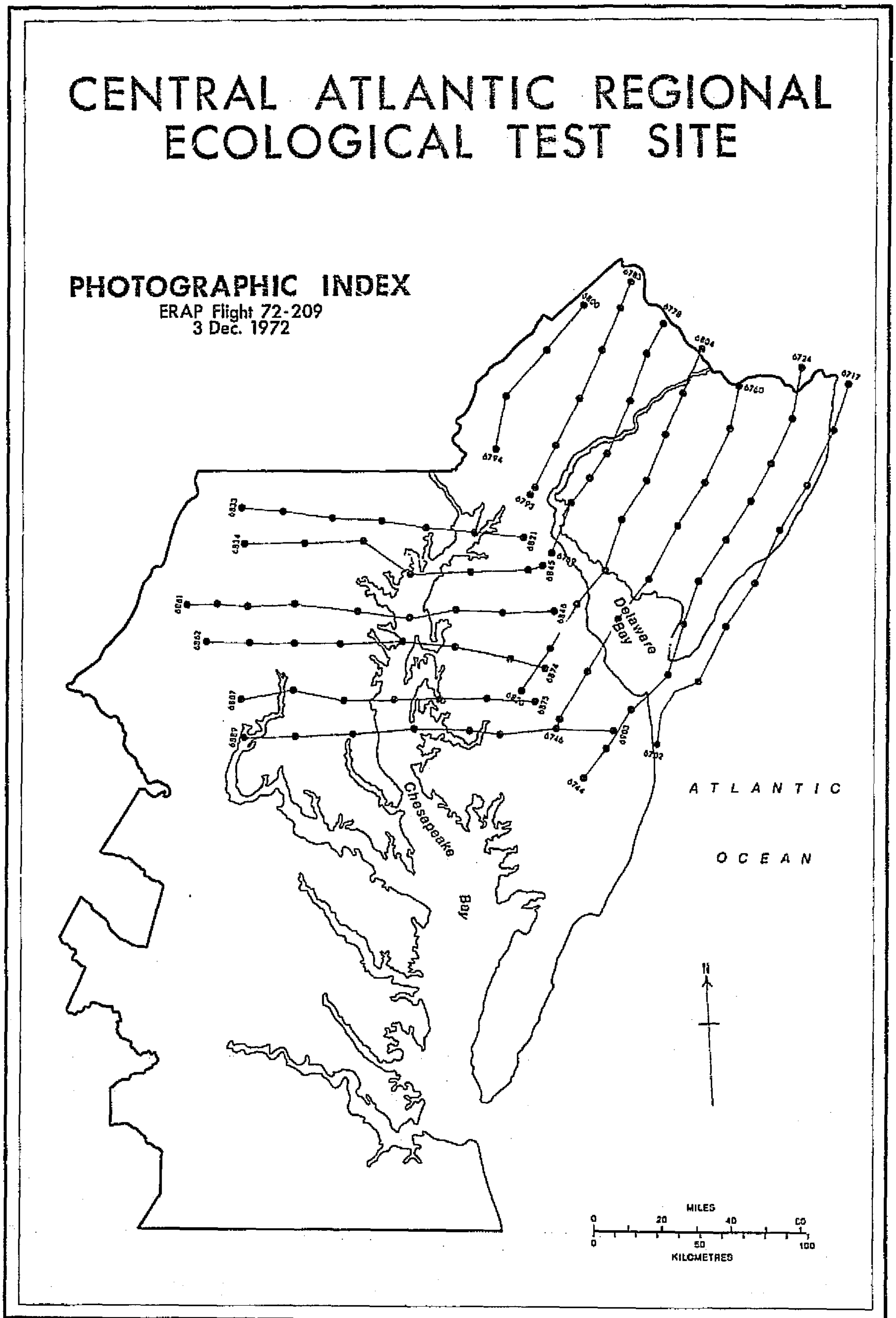

CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHOTOGRAPHIC INDEX
ERAP Flight 72-209
3 Dec. 1972
Delaware Bay
Chesapeake
Bay
ATLANTIC
OCEAN
N
MILES
0
20
40
KILOMETRES
0
50
100

Figure 7.

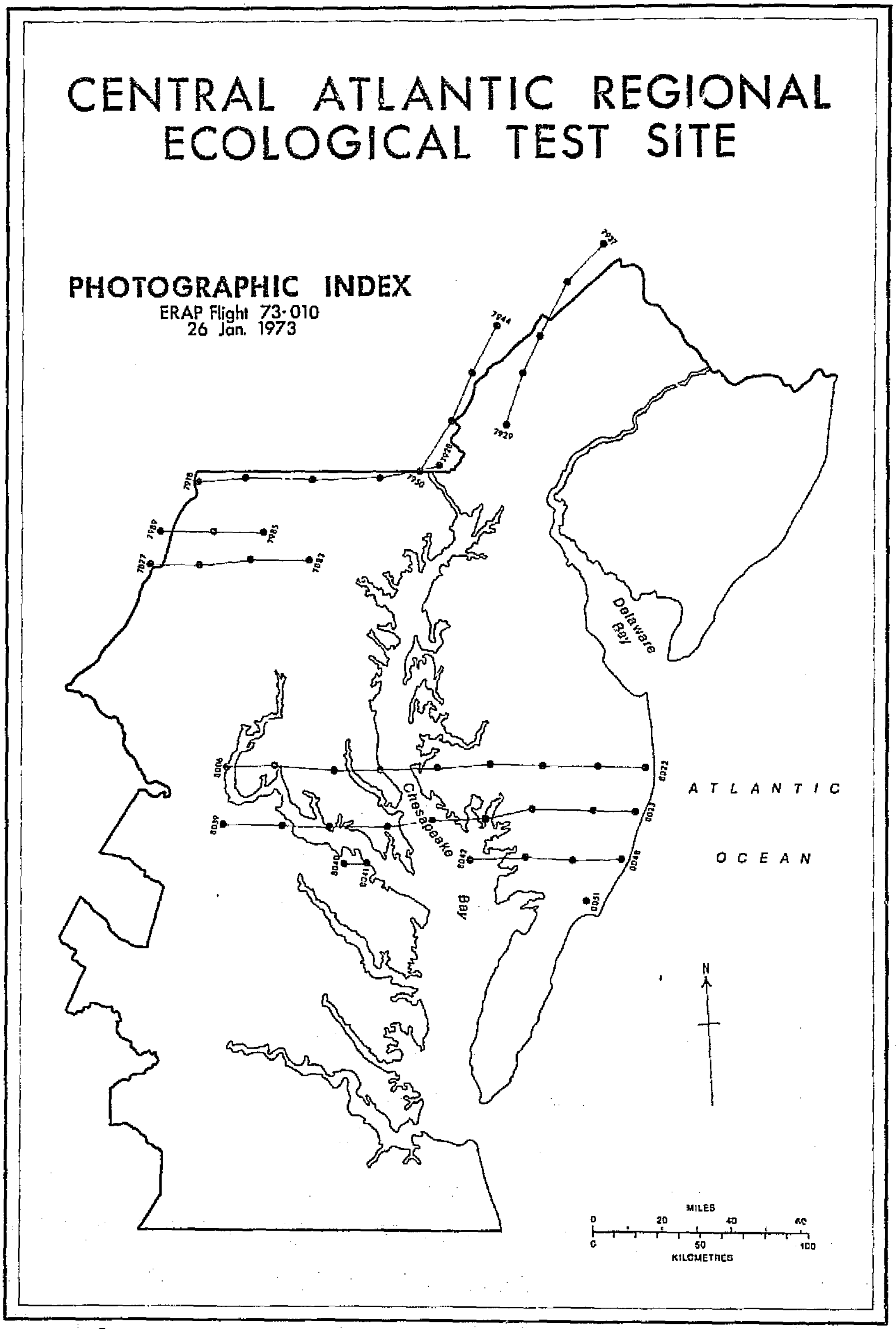

CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHOTOGRAPHIC INDEX
ERAP Flight 73-010
26 Jan. 1973
Delaware
Bay
Chesapeake
Bay
A T L A N T I C
O C E A N
N
MILES
0
20
40
60
50
100
KILOMETRES

Figure 8.

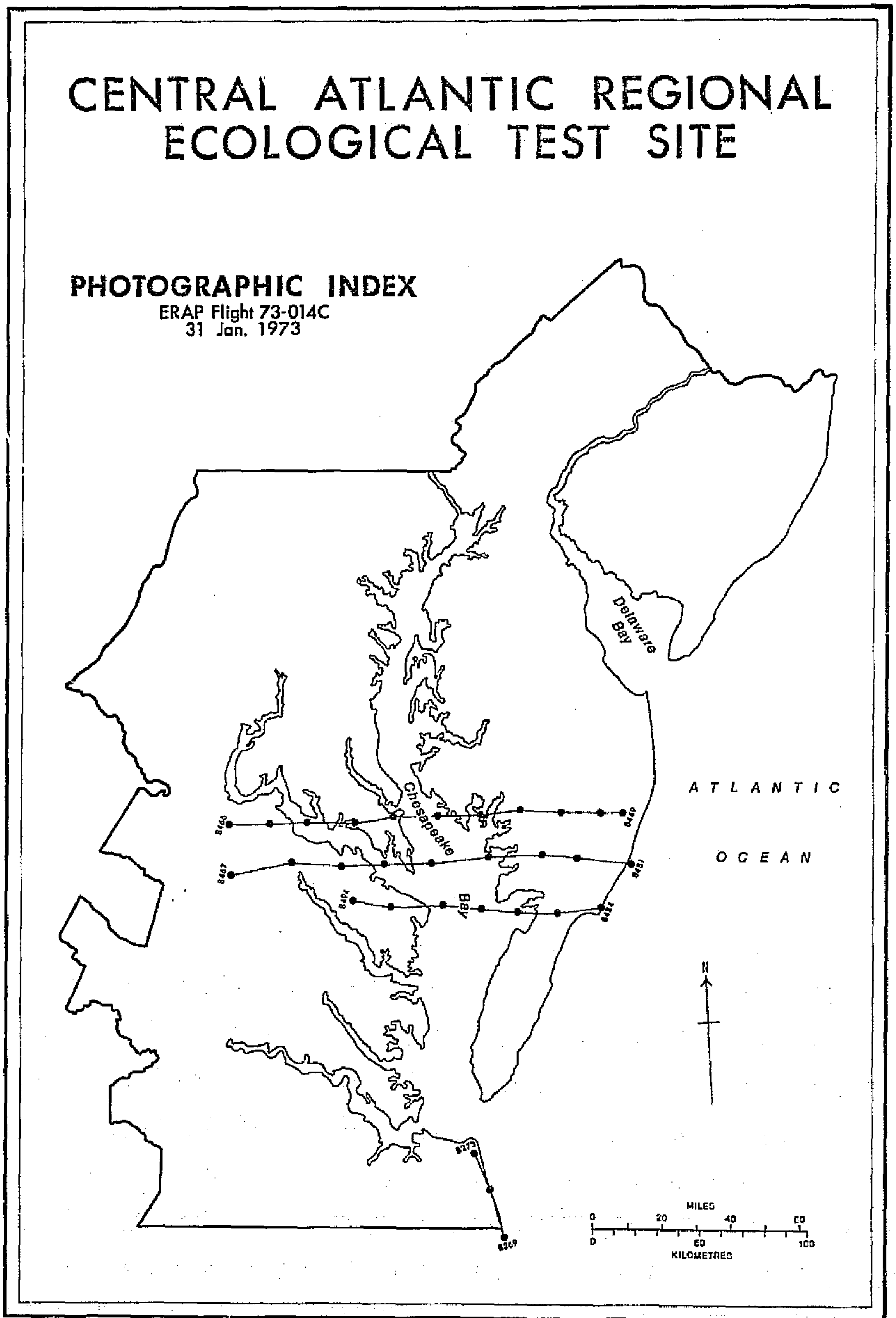

CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHOTOGRAPHIC INDEX
ERAP Flight 73-014C
31 Jan. 1973
Delaware Bay
Chesapeake Bay
ATLANTIC
OCEAN
N
MILES
KILOMETRES

Figure 9.

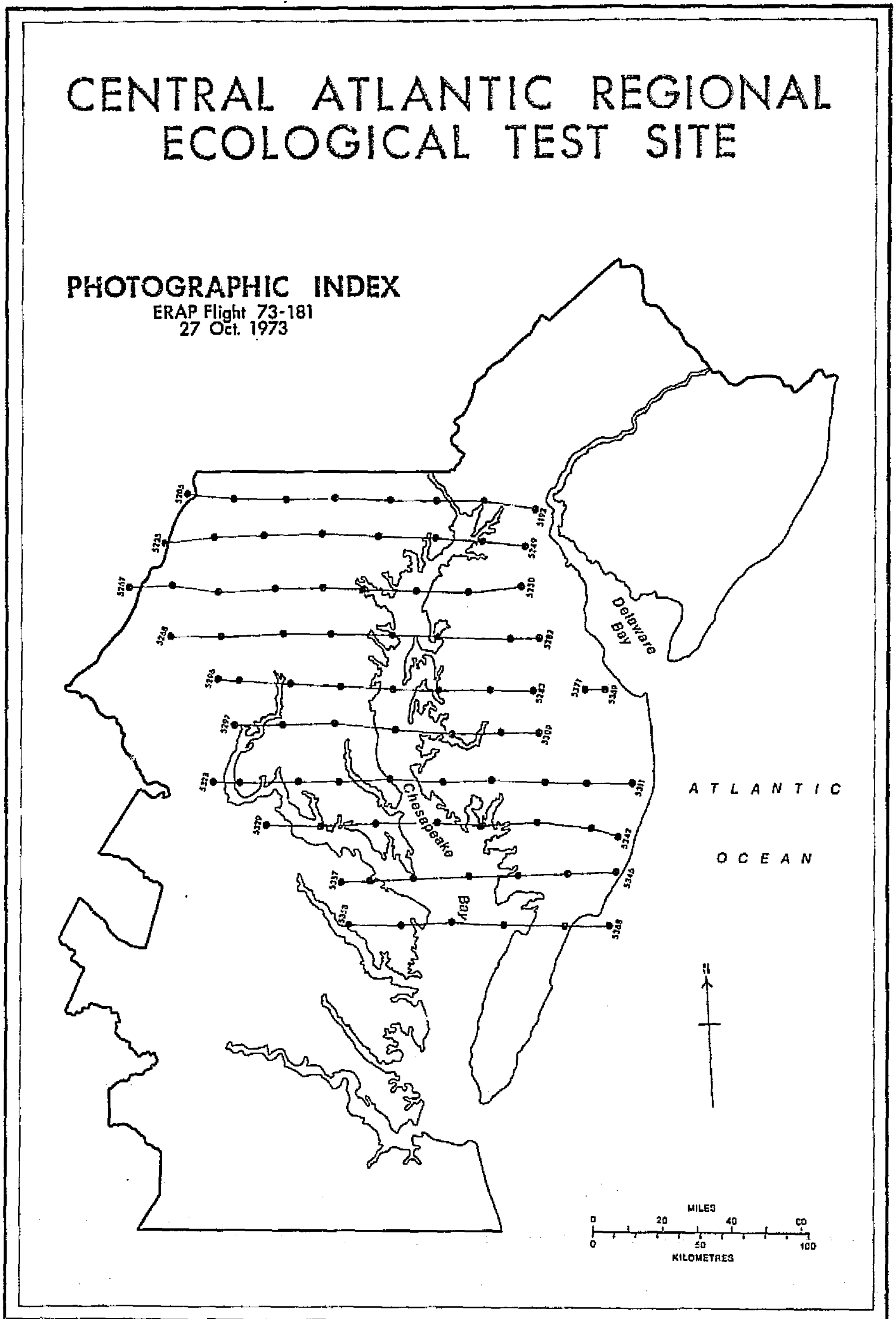

CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHOTOGRAPHIC INDEX
ERAP Flight 73-181
27 Oct. 1973
Delaware Bay
Chesapeake
Bay
ATLANTIC
OCEAN
MILES
0 20 40 60
0 50 100
KILOMETRES

Figure 10.

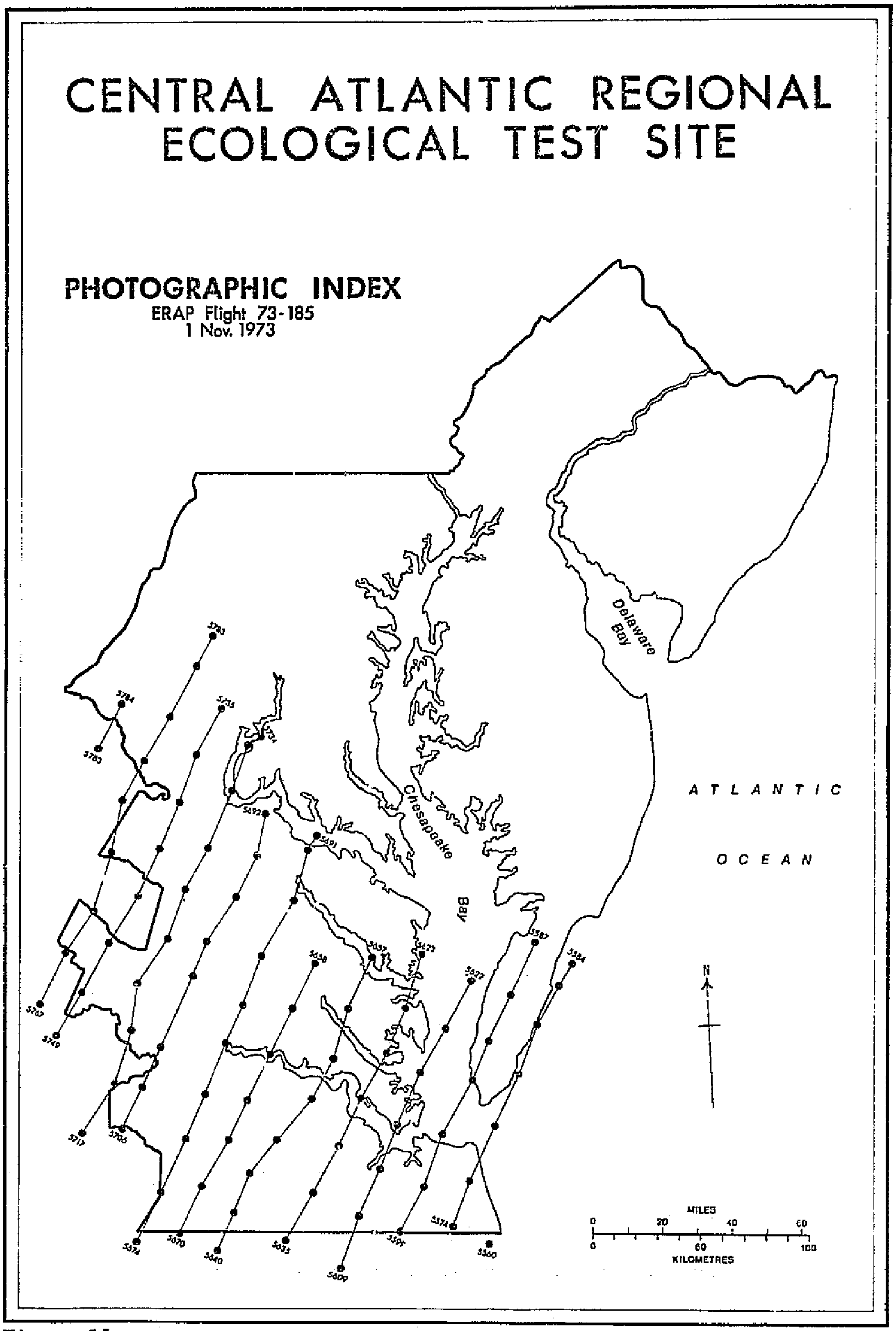

CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHOTOGRAPHIC INDEX
ERAP Flight 73-185
1 Nov. 1973
Delaware Bay
Chesapeake Bay
ATLANTIC OCEAN
N
MILES
0 20 40 60
0 60 100
KILOMETRES

Figure 11.

## PREPARATION OF PHOTOMOSAICS

A preliminary step in the land use compilation process is the preparation of a plotting base on which to map land use. Such a base is needed as a locational or positional quide, and as such, should have a high locational accuracy. CARETS investigators decided to produce a series of photomosaics from NASA missions 144, 145, and 166 high-altitude aircraft photography. Figure 12 presents an index to the CARETS photomosaic sheets and 1:100,000 land use maps and overlays.

USGS photogrammetrists constructed the CARETS photomosaics from geometrically rectified black and white stable base positive transparencies at a scale of 1:100,000. Measuring 50 cm on a side, and overlaid with a 1 $cm^2$ grid, these photomosaics are keyed to the Universal Transverse Mercator Zone 18. Geographic tick marks at 5-minute intervals were also provided as additional locational references. A sample of the CARETS photomosaics is presented in figure 13.

Because Missions 144, 145, and 166 did not cover the entire CARETS region, the original series of photomosaics was incomplete. Figure 14 indicates areas of incomplete 1970 high-altitude aircraft coverage resulting from a lack of photography or extensive cloud cover. The largest such areas were in New Jersey (where no coverage existed for the Toms River and Little Egg Harbor sheets) and in the southwestern portion of the CARETS region. For most areas of imcomplete coverage, photogrammetrists constructed incomplete mosaics to allow the mapping of as much of the CARETS area as possible. When 1972 high-altitude aircraft photography (Flights 147, 208, and 209) became available, new mosaics were constructed for all sheets having areas of incomplete coverage.

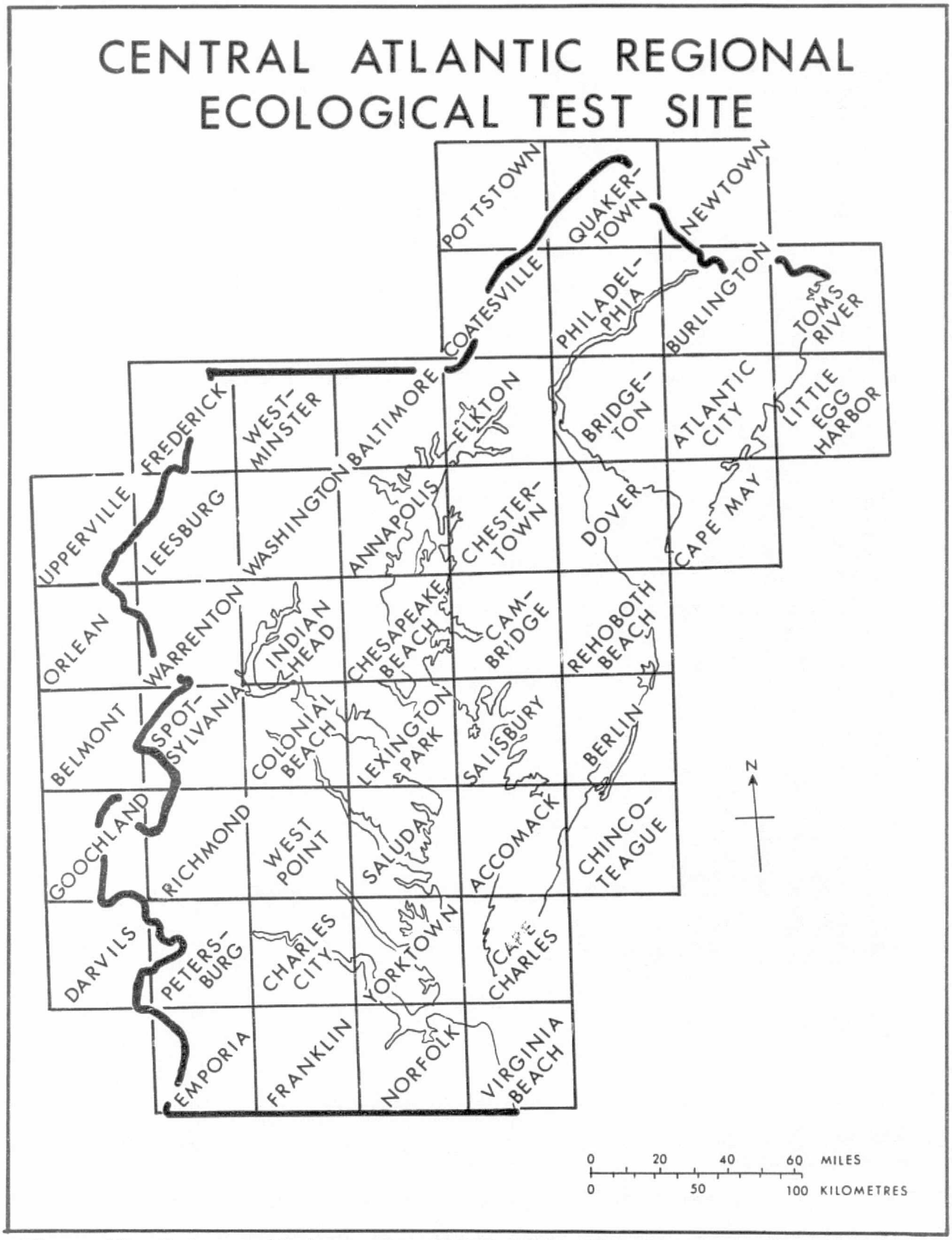
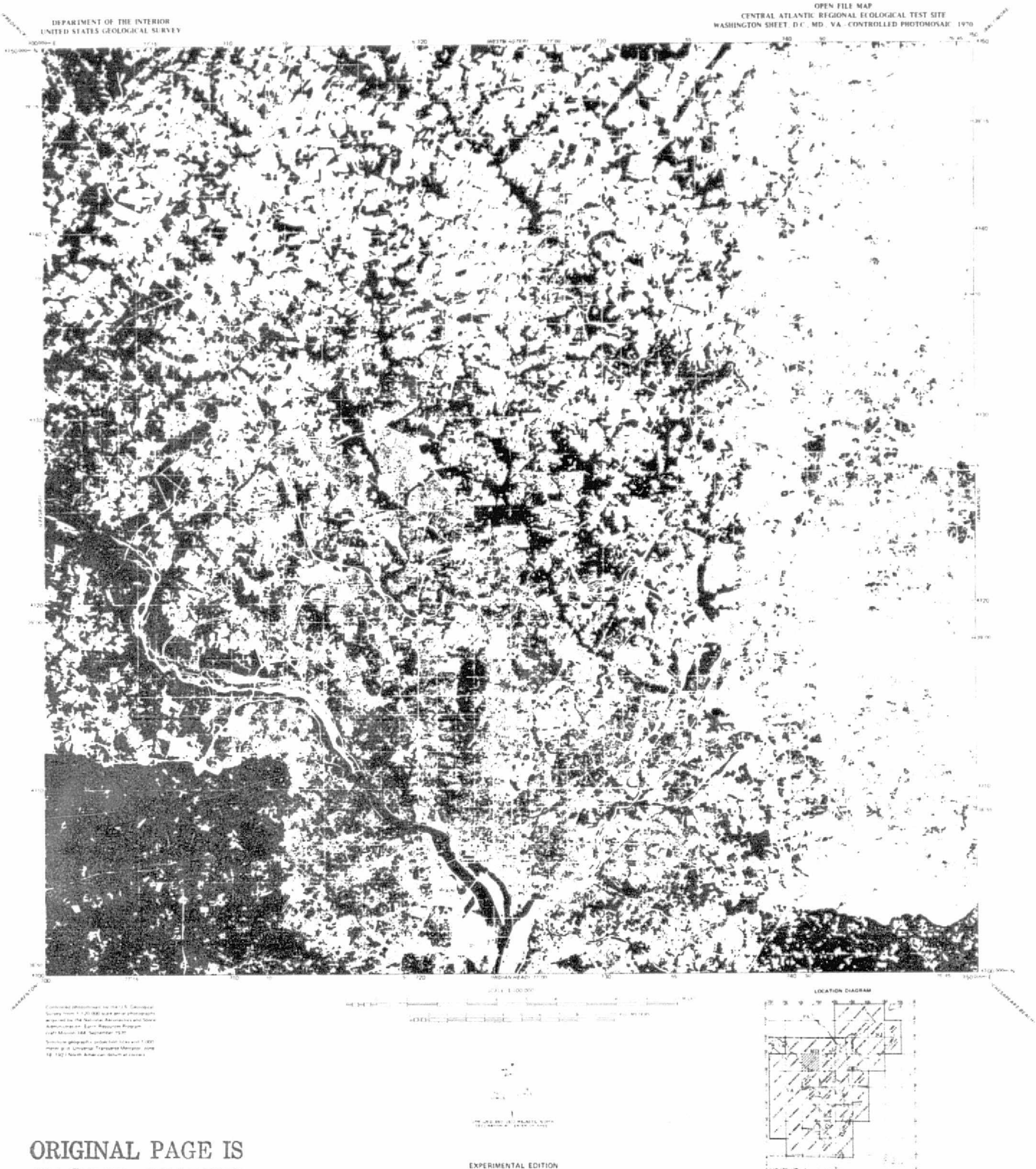



Figure 12 -- Index to 48 sheets for CARETS 1:100,000 scale data base.

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OF POOR QUALITY

CONTROLLED PHOTOMOSAIC, 1970, OF THE WASHINGTON SHEET, D.C., MD., VA.
1973

Figure 13. Reduced specimen sheet, controlled photomosaic

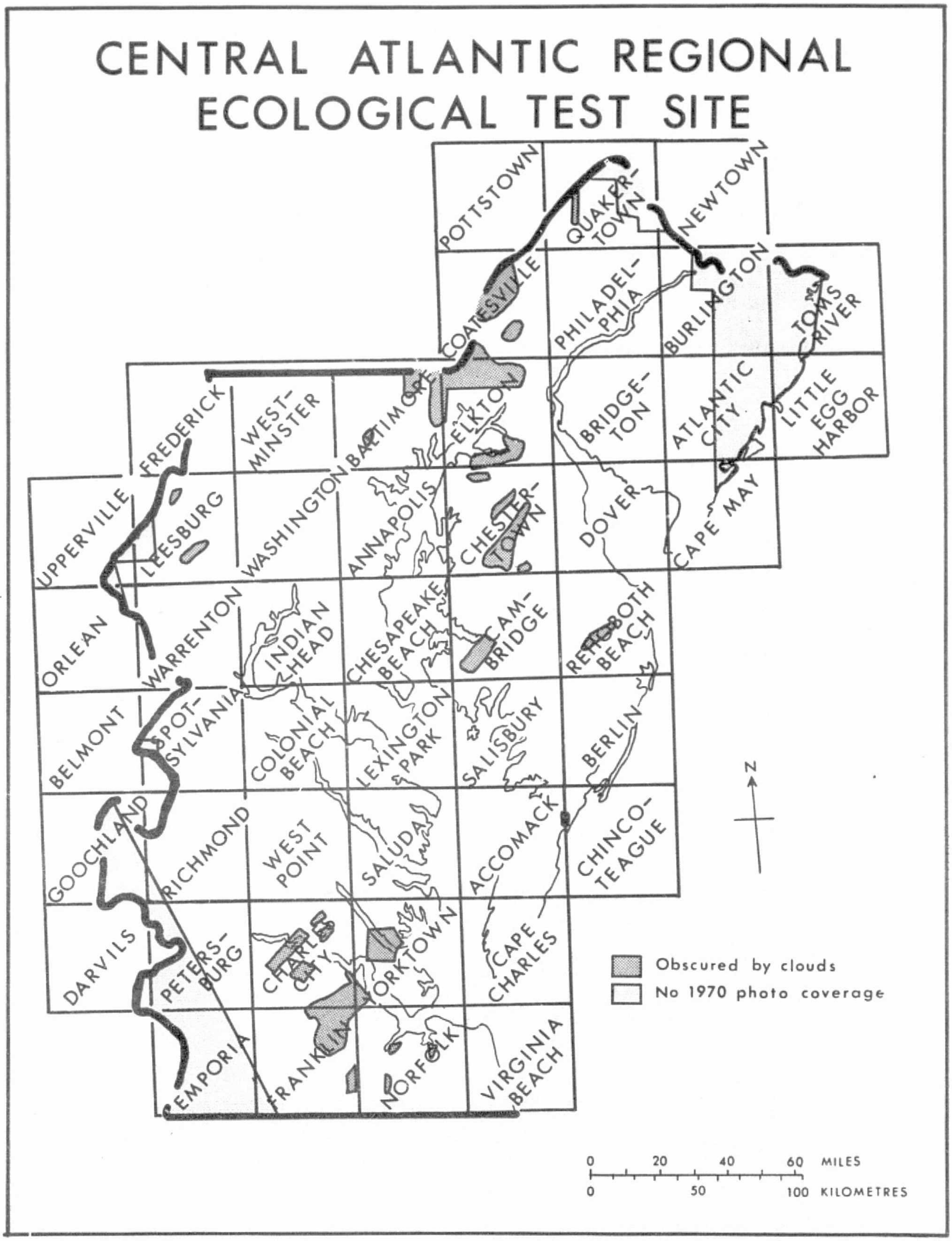



Figure 14 --Areas of CARETS not covered by 1970 high-altitude aircraft photography.

Limited testing for cartographic accuracy of these mosaics revealed that 90 percent of the well-defined points were estimated to within 1 mm of their true positions. At a scale of 1:100,000, 1 mm represents 100 m on the ground. This error exceeds by two times the error permitted by U.S. National Map Accuracy Standards. Becaus: these mosaics were not intended to be final products, but rather a step in the mapping process, they lack the careful tonal matching from print to print that is characteristic of USGS published mosaics.

## DEVELOPMENT OF THE LAND USE CLASSIFICATION SCHEME

The land use classification scheme used in the CARETS project resulted from research into the needs for land use information and the capabilities of remote sensor data for land use mapping. Before the development of the CARETS classification, the USGS Geographic Applications Program (GAP) sponsored 5 years of contractual research by universities and working groups of the Association of American Geographers (AAG). This research involved literature searches, multidisciplinary contacts, and studies of land use policy legislation introduced in Congress during that period.

During the AAG contract work, Anderson (1971) proposed two tentative land use classification schemes for small scale (1:2,500,000) land use maps. These are presented in tables 2 and 3. Scheme I (table 2) assumes the availability of orbital imagery and supplemental information, whereas scheme II (table 3) assumes little or no supplemental information. These activity-oriented schemes bear some resemblence to the two-level classification later developed.

Concurrently with AAG researchers, Wray, in conducting research in the GAP Census Cities experiment, developed a scheme designed for land use and land use change mapping for metropolitan areas (table 4). This scheme provides greater detailed urban categories and was designed for use with the mapping of urbanized areas rather than the whole country.

In early 1971 the Geographic Applications Program organized the Inter-Agency Steering Committee on Land Use Information and Classification. Supported by NASA and the USGS, the committee consisted of

Table 2

Scheme I

A tentative classification scheme for use with orbital imagery and with some supplementary information for making land use maps for the United States ranging in scale from 1:250,000 to 1:2,500,000.

This scheme assumes availability of some supplementary information from other sources. Vegetal cover terminology is given in parenthesis where applicable.

I Resource Production and Extraction

A. Agricultural

(1) Crop Production (Cropland)

(Cropland harvested except for orchards, groves, and vineyards; cropland used only for pasture; and cropland not harvested and not pastured)

(a) Irrigated Crop Production

(b) Non-Irrigated Crop Production

(2) Fruit and Nut Culture (Orchards, Groves, Vineyards)

(a) Irrigated Fruit and Nut Culture

(b) Non-Irrigated Fruit and Nut Culture

B. Grazing (Grassland and Shrubland)

(1) Rangeland Grazing (Rangeland)

(Native grasses, shrubs and brushland including sagebrush, scattered mesquite and some other shrub types in the West)

(2) Livestock Pasturing (Pasture)

(Tame grasses and legumes and scattered brushland in the East)

C. Forestry

(1) Non-Commercial Tree Raising (Arid Woodland)

(Generally of little commercial value for timber or wood products but may be of value for watershed protection, grazing, wildlife habitat and recreation)

Table 2--(continued)

D. Mining and Quarry

II Transportation, Communication, and Utilities

A. Motoring (Highways)

B. Railroading (Railroads)

C. Flying (Airports)

D. Communication and Utility Activity (Communication and Utilities)

III Urban Activities

A. Urbanized Livelihood Areas (Urbanized Land)

(1970 definition not yet determined by the Bureau of the Census)

(1) Industrial (Industrial Land)

(2) Commercial (Commercial Land)

(3) Residential (Residential Land)

(4) Other Livelihood (Other Urban Land)

B. Other Urban Livelihood (Other Urban Land)

(Populated places of more than 2,500 but not including urbanized areas)

IV Towns and Other Built-up Livelihood Areas (Town and Built-up Land)

(With a lower areal limit which is identifiable through interpretation)

V Recreation Activities

A. Mountain Oriented (Mountains)

B. Water Oriented (Water Bodies)

C. Desert Oriented (Desert)

VI Low-Activity Areas (Other Land)

(Excluding land of these types on which land using activities are found)

A. Low-Activity Marshland Oriented (Marshland)

B. Low-Activity Tundra Oriented (Tundra)

Table 2--(continued)

C. Low-Activity Barren Land Oriented (Barren Land) including lava flows and mountain peaks above timber line.

VII Water Using Activities (Water Bodies)

Source: Anderson, 1971

Table 3

Scheme II

A tentative classification scheme for use with orbital imagery but with little or no supplementary information for making land use maps ranging in scale from 1:250,000 to 1:2,500,000.

This scheme assumes little or no supplementary information from other sources but the assumption is made that vegetal cover surrogates can be effectively used to identify these activity-oriented uses.

I Agricultural (with no distinction attempted between cropland and orchards, groves, and vineyards and between irrigated and non-irrigated)

II Grazing

III Forestry

IV Mining and Quarrying

V Transportation, Communications, and Utilities (first order only)

VI Urban Activities

VII Recreational (only if mountains, water bodies, desert, etc., are used as surrogates and only if inference by knowledgeable persons is employed)

VIII Low Activity Areas (Other Land)
(marshland, tundra and barren land excluding those classified by use of surrogates and inference as recreational)

IX Water Using Activities (Water Bodies)

Source: Anderson, 1971

Table 4--Census cities land use classification

| | |
|---|---|
| Livelihood | |
| | Primarily industry |
| | Extractive industry |
| | Commercial and services |
| | Strip and cluster development |
| Residential | |
| | Multi-family residence |
| | Single-family residence |
| Other, mostly open | |
| | Improved open space |
| | Unimproved open space |
| | Unimproved wetland |
| | Agriculture with residence |
| | Water |

representatives of the USGS, NASA, the U.S. Department of Agriculture Soil Conservation Service, the Association of American Geographers, and the International Geographical Union (Anderson and others, 1972). The committee continued the investigation into the development of a standardized land use classification scheme.

From June 28 to 30, 1971 the Interagency Steering committee conducted a conference on land use that attracted representatives of public agencies and private organizations throughout the country. Among the objectives of the conference was obtaining responses to the following questions:

(1) How can the needs of Federal agencies be met for an up-to-date overview of land use throughout the country on a basis that is uniform in data, scale, and categorization at the first and second orders?

(2) How can we utilize the best features of existing widely used classification schemes?

(3) How can we best devise an open-ended classification that permits further development at third and fourth digit levels and still have capability with a national system of classification?

(4) What classification framework will be most receptive to data from instrumented satellite and high-altitude aircraft platforms?

Out of this conference and the other work of the Inter-Agency Steering Committee came the land use classification presented in USGS Circular 671 (Anderson and others, 1972) (table 5).

Table 5--U.S. Geological Survey land use classification system for use with remote sensor data*

| Level I | Level II |
|---|---|
| 1 Urban and built-up | 1 Residential |
| | 2 Commercial and Services |
| | 3 Industiral |
| | 4 Extractive |
| | 5 Transportation, Communications and Utilities |
| | 6 Institutional |
| | 7 Strip and Clustered Settlement |
| | 8 Mixed |
| | 9 Open and Other |
| 2 Agricultural Land | 1 Cropland and Pasture |
| | 2 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas |
| | 3 Feeding Operations |
| | 4 Other |
| 3 Rangeland | 1 Grass |
| | 2 Savannas (Palmetto Prairies) |
| | 3 Chaparral |
| | 4 Desert Shrub |
| 4 Forest Land | 1 Deciduous |
| | 2 Evergreen |
| | 3 Mixed |
| 5 Water | 1 Streams and Waterways |
| | 2 Lakes |
| | 3 Reservoirs |
| | 4 Bays and Estuaries |
| | 5 Other |
| 6 Nonforested Wetland | 1 Vegetated |
| | 2 Bare |
| 7 Barren Land | 1 Salt Flats |
| | 2 Beaches |
| | 3 Sand Other than Beaches |
| | 4 Bare Exposed Rock |
| | 5 Other |
| 8 Tundra | |
| 9 Permanent Snow and Ice Fields | |

*Anderson and others, 1972

The scheme used by the CARETS project is an earlier version of the Circular 671 classification, differing only slightly from the later published version (table 6). The CARETS classification defines Level II forest categories 41 and 42 by percent crown cover, whereas the Circular 671 classification has Level II categories for deciduous, coniferous, and mixed forests (categories 41, 42, and 43, respectively). A minor difference between the two schemes is the differing arrangements of Level II barren land categories: 72, 73, and 74. The difficulty CARETS interpreters encountered in category 42, light crown cover forest, because of the variable appearance of such areas during different seasons and stages of forest growth, resulted in serious accuracy problems for that category. Even before publication of Circular 671, the authors substituted deciduous, coniferous, and mixed forests categories for percentage crown cover.

Input from user agencies and the experience of land use interpreters in Geography Program projects led to the revision of the USGS classification (Anderson and others, 1976). This revised scheme is presented in table 7.

Table 6—Land use categories in the Central Atlantic Regional Ecological test site data base

| Level I Categories and Map Notation Used | Level II Categories and Map Notation Used |
|---|---|
| 1 Urban & Built-up | 11 Residential |
| | 12 Commercial and Services |
| | 13 Industrial |
| | 14 Extractive |
| | 15 Transportation, Communications, and Utilities |
| | 16 Institutional |
| | 17 Strip and Clustered Settlement |
| | 18 Mixed |
| | 19 Open and Other |
| 2 Agricultural | 21 Cropland and Pasture |
| | 22 Orchards, Groves, Bush Fruits, Vineyards, and Horticultural Areas |
| | 23 Feeding operations |
| | 24 Other |
| 4 Forest Land | 41 Heavy crown cover (over 40%) |
| | 42 Light crown cover (10% to 40%) |
| 5 Water | 51 Streams and Waterways |
| | 52 Lakes |
| | 53 Reservoirs |
| | 54 Bays and Estuaries |
| | 55 Other |
| 6 Nonforested Wetland | 61 Vegetated |
| | 62 Bare |
| 7 Barren Land | 72 Sand Other than Beaches |
| | 73 Bare exposed rock |
| | 74 Beaches |
| | 75 Other |

Table 7--U.S. Geological Survey land use and land cover classification system for use with remote sensor data*

| LEVEL I | LEVEL II |
| --- | --- |
| 1 Urban or Built-up Land | 11 Residential |
| | 12 Commercial and Services |
| | 13 Industrial |
| | 14 Transportation, Communications and Utilities |
| | 15 Industrial and Commercial Complexes |
| | 16 Mixed Urban or Built-up Land |
| | 17 Other Urban or Built-up Land |
| 2 Agricultural Land | 21 Cropland and Pasture |
| | 22 Orchards, Groves, Vineyards, Nursuries, and Ornamental Horticultural Areas |
| | 23 Confined Feeding Operations |
| | 24 Other Agricultural Land |
| 3 Rangeland | 31 Herbaceous Rangeland |
| | 32 Shrub and Brush Rangeland |
| | 33 Mixed Rangeland |
| 4 Forest Land | 41 Deciduous Forest Land |
| | 42 Evergreen Forest Land |
| | 43 Mixed Forest Land |
| 5 Water | 51 Streams and Canals |
| | 52 Lakes |
| | 53 Reservoirs |
| | 54 Bays and Estuaries |
| 6 Wetland | 61 Forested Wetland |
| | 62 Nonforested Wetland |
| 7 Barren Land | 71 Dry Salt Flats |
| | 72 Beaches |
| | 73 Sandy Areas Other than Beaches |
| | 74 Bare Exposed Rock |
| | 75 Strip Mines, Quarries, and Gravel Pits |
| | 76 Transitional Areas |
| | 77 Mixed Barren Land |
| 8 Tundra | 81 Shrub and Brush Tundra |
| | 82 Herbaceous Tundra |
| | 83 Bare Ground Tundra |
| | 84 Wet Tundra |
| | 85 Mixed Tundra |
| 9 Perennial Snow or Ice | 91 Perennial Snowfields |
| | 92 Glaciers |

*Anderson and others, 1976

## INTERPRETATION AND MAPPING FOR 1970 LAND USE DATA FROM HIGH-ALTITUDE AIRCRAFT PHOTOGRAPHY

CARETS interpreters compiled land use data from high-altitude aircraft photography on frosted mylar drafting film overlays. The drafting film was registered to the photomosaics using the USGS standard punch format and registration pins. In addition, grid-intersection tick marks were placed at the four grid corners on each overlay. In the land use compilation process interpreters used an 8-power monocular hand lens to view the film transparency on a light table. Identifying the land use on the photography, they marked the boundaries on the drafting film over the corresponding land use area on the mosaic and then penciled in the identified land use in each polygon with a two-digit number.

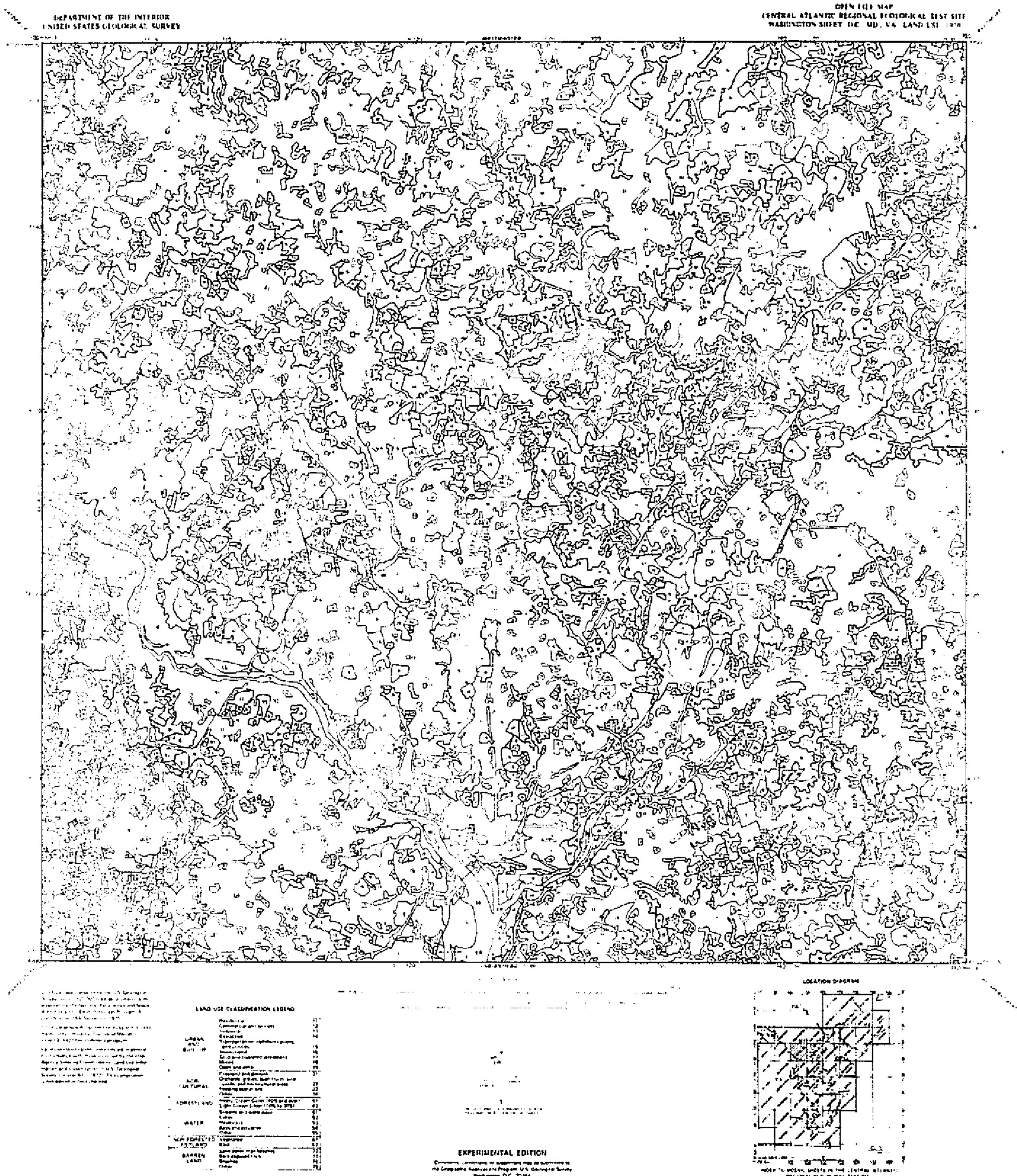
CARETS investigators established a minimum recording size of 2 mm (200 m on the ground) and thus interpreters incorporated into surrounding or neighboring polygons any land use areas with dimensions smaller than 2 mm. This practice eliminates many important landscape features such as roads, streets, and streams that are too narrow to record.

Besides using color and color infrared photography, the interpreters also used city, county, and State road maps, regional and planning district maps and 1:24,000 and 1:250,000 series USGS topographic sheets as supplementary sources of information to aid in identification.

The lack of complete high-altitude aircraft photographic coverage of the CARETS region for 1970 created problems for the land use compiler as well as the photogrammetrist constructing the CARETS photomosaics. To obtain the missing land use information, CARETS investigators ordered

aerial photographic coverage (in the form of indexes dating as close to 1970 as possible) from the U.S. Department of Agriculture Agricultural Stabilization and Conservation Serivce (ASCS). When 1972 high altitude photography became available, the new mosaics were constructed and 1972 land use was mapped for the areas previously unmapped. Interpreters then used the 1972 land use interpretations and the black and white ASCS photography indexes to detect areas of change. In this study, the interpreter compared the map with the photography and recorded on the map the land use differences he found.

Upon completion of land use mapping, CARETS researchers used two procedures to edit the manuscript maps: (1) the systematic study of the entire mapped area of each sheet and (2) a careful matching of the unconnected line segments on each side of adjoining sheet margins. Editing for interpretation and mapping completeness concentrated on the correct identification of each land use, correct labelling of each land use complex, completeness of land use boundaries, and elimination of mapped areas below the minimum mapping size. Figure 15 presents a reduced specimen of a CARETS Level II land use map.




LAND USE MAP IN 1970 OF THE WASHINGTON SHEET, D.C., MD., VA.
1973

Figure 15.

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OF POOR QUALITY

## PHOTOINTERPRETATION KEY FOR USE WITH HIGH-ALTITUDE PHOTOGRAPHY IN CARETS

Land use classification (using a preliminary version of USGS Circular 671, table 6) of high-altitude photography involves a series of decisions, each limiting the possibilities of classification until a final Level II identifier is applicable. When beginning a land use map, the interpreter should first examine each piece of film for the major land use types, such as urban land, agricultural land, forest land, wetlands, or water. The general appearance of surface features on 1:120,000-scale photography is similar to the human eye view from a medium-altitude aircraft. Urban land is recognized by the patterns of buildings, houses, road networks, railroad yards, and other man-made features, creating a pattern contrasting strongly with the less complex signatures of agricultural fields, forest land, wetlands, and water.

Within the urban context many Level II land use types are easily recognizable. Others, however, require a classification decision based on visible clues. These clues are a combination of estimated building size, parking facilities, presence of adjacent facilities or buildings, road patterns, railroad patterns, and a basic knowledge of land use patterns as they appear on the ground.

Residential land (category 11) is characterized by single-family homes arranged along a road or in a subdivision. The subdivision is the most easily recognized residential land because all homes are of a standard size and are evenly spaced. The road patterns often have limited outlets to main thoroughfares and have numerous driveways. In developments where the homes are more widely scattered, a 4-hectare area with at least four homes would be classificed as residential.

Other residential land includes garden apartments, townhouses and high rise apartment buildings. Garden apartments and townhouses appear on the photography as a series of building units arranged on a lot usually with well groomed grass, and parking lots and sometimes swimming pools.

Residential areas of high rise apartments are the most difficult to identify. Occassionally they are landscaped and have tennis courts and swimming pools. When no additional clues are available, however, high rise apartments may be misclassified as commercial and service land use.

Commercial and Service land use (category 12) encompasses many different facilities, including urban central business districts, suburban shopping centers, commercial strips, wholesale warehouses, recreational building facilities, gas stations, motels, and restaurants. Frequently the recognizable signatures of the commercial land use is the larger building size and parking space and access to major highways and railroads. In the central business districts, commercial land uses have a darker spectral response than the overall urban area.

Industrial areas (category 13) also vary considerably in appearance. Areas occupied by light industries are frequently mistaken for commercial land use. The most easily identified industrial areas consist of complexes having heavy equipment, fuel tanks, steam or smoke emission. Such heavy industry is frequently located along rail lines or navigable water bodies or both.

Extractive land (category 14) has a bright signature on color infrared film. Many extractive operations have dimensions smaller than 200 m and thus are too small to be mapped at a scale of 1:100,000.

Extractive uses include sand and gravel pits, stone quarries, underground mines, and wells. In the CARETS region extractive uses occur predominantly on the land surface. Stone quarries are often identifiable as gray pits with step-like terraces. Sand and gravel pits are less distinctive. They are often confused with areas newly cleared of trees or under construction or land fill operations. Because of such ambiguities, the revised USGS land use classification scheme (Anderson and others, 1976) considers extractive land a subcategory of barren land rather than of urban and built-up land.

The transportation, communication and utilities land use (category 15) includes all roads, parking lots, highway interchanges, airport runways and taxiways, railroads and railroad yards, dockyards, radio towers, powerline rights-of-way and power substations. These patterns are recognized on the photography much as they would be from the air. A swath of land approximately 2 mm wide on the film, cutting through forest residential areas, or other land, is most likely a powerline or pipeline right-of-way. Only features at least 2 mm wide on the photography are mapped, and thus a cultural feature overlay to the land use maps is helpful. A cloverleaf interchange occupying more than 4 hectares of land is mapped as transportation. Airports are easily identified as patterns of paved runways surrounded by grass fields, ground facilities, hangers and parking facilities. Harbor facilities are also included in the transportation category and are easily identified by features such as piers extending into the water, heavy loading equipment, fuel storage tanks, dry docks, rail connections and rail yards.

Institutional land uses (category 16) include schools, hospitals, correctional and penal institutions, and other government facilities. Institutional facilities usually are identified by a large building or complex of buildings in a landscaped or campus setting. Some parking facilities are commonly available. Schools are recognized by their athletic fields and grounds, and their locations within a residential area. Auxiliary sources such as 1:24,000-scale maps are also helpful in locating schools, churches, prisons, and other public facilities.

Strip and clustered settlements (category 17) are patterns of settlements where no single land use predominates. Frequently a small town or community along a highway will be large enough to map using a single land use classifier. These communities are characterized by a cluster of houses and additional buildings such as churches, schools, and stores.

The urban mixed category (category 18) occurs wherever a mixture of urban land types exists in cities with a population greater than 50,000 and no single category predominates. Such a condition exists where several uses occur side by side but none is greater than one third of the total area.

Within urban areas open parkland, golf courses, cemeteries, athletic fields, and vacant lots are classified as urban open land (category 19). On the color infrared film, golf course fairways appear red and circular greens dark red. Well kept parkland also has a bright red signature, but open land or athletic fields appear duller red. Baseball diamonds are easily identified by their shape. Cemeteries appear like parkland but often have numerous monuments and winding roads.

How agricultural land appears on color infrared photography depends upon the season, the crop cultivated, and its stage of growth. The prominent signature is not so much the red color of healthy vegetation as field patterns, which may be irregular, rectilinear, or in contour strips. Fields are frequently outlined by trees.

In the Central Atlantic region most agricultural land is cropland and pasture (category 21). Fields with regularly spaced lot patterns normally have fruit trees or bushes, which are classified as orchards, groves and bush fruit areas (category 22). Orchards appear on 1:24,000-scale topographic maps, and such maps are often useful for identifying orchards.

Areas where large numbers of animals are confined in a small space, such as feed lots, poultry farms, dairy farms, and pig farms, are classified as feeding operations (category 23). One can recognize such agricultural operations by dirt fields and pens surrounding large farm buildings. Poultry operations often occur in a series of long rectangular buildings.

The category "other agricultural" (category 24) is used for less common agricultural types such as mushroom farms and fish hatcheries. Mushroom farming is an indoor operation, conducted in "cellers" resembling poultry barns. Fish hatcheries may be recognized as inundated fields, surrounded by small dikes, appearing blue or black on the photography. They are frequently confused with flooded quarries, sewage ponds, and waste water ponds. Topographic maps at a scale of 1:24,000 are useful as an auxiliary source of information for difficult-to-identify features.

Forest land is most easily identified as a full stand of trees. On color infrared photography, forest land appears a dark red and has greater texture than agricultural land. Heavy crown cover forest (category 41) can be readily identified and is often mapped first. Occassionally a

mature orchard is misclassified as forest, but one can use a topographic map to identify many orchards.

Light crown cover forest (category 42) is difficult to identify, because it emcompasses stages of forest growth including abandoned cropland, pasture, clear cut areas reverting to forest, and fields of scattered mature trees. No single recognizable feature characterizes the light crown cover forest, but some signature patterns predominate. The color tones of light crown cover forest on the color infrared photography are similar to those of the heavy crown cover forest. Occasionally low crown cover forest will appear less red and more of a mottled color as more of the earth and urderbrush is visible through the crown cover. Occassionally the tree tops of a light crown cover forest appear lower than the tree tops of heavy crown cover forest.

The water categories are those most easily identified on the color infrared photography because water absorbs infrared rays and boundaries between water and land are sharp. Water bodies usually appear dark blue or black.

Difficulties in interpreting the water categories arise because of the need to define boundaries between estuaries (cateogry 54) and rivers (category 51) and between the ocean and bays. Such distinctions cannot be made by signature differences but by size limitations. In mapping the CARETS region, interpreters separated estuaries from the ocean by drawing a straight line connecting headlands. They separated the estuaries from streams at the fall line. Natural lakes (category 52) are distinguished from reservoirs (category 53) by the absence of artificial impoundments. One can recognize dams by the straight edge at one end

of the reservoir they create and by the stream or creek continuing downstream. Many of the reservoirs in the CARETS area are waste-water holding ponds.

In the CARETS region nonforested wetlands usually occur in low lying areas along coasts and flood plains. They often are riddled with canals and narrow drainage ditches. Vegetated nonforested wetlands may be distinguished from agricultural land by their lack of field patterns. Like agricultural land, vegetated nonforested wetlands (category 61) may appear red, green, brown, or various other colors. Often islands of dry grassland occur within wetlands. Bare wetlands (category 62) appear dark, are located at the waters edge and lack a red color from healthy vegetation.

Barren land encompasses all land temporarily or permanently lacking vegetation or cultural features. Beach sand (category 72) often consists of sand deposited primarily by water. It appears white along the coast and has high reflectance. Sand other than beaches (category 73) appears like beach sand but consists primarily of unstabilized wind-deposited dunes. Bare exposed rock (category 74) is not as highly reflective as sand and has a gray-blue signature on the color infrared photographs.

One caveat must be extended concerning the use of color infrared photography. Not all such photography has the same color signatures as those discussed above. The uses may vary, but colors are consistent among frames from the same batch of properly stored film.

## FIELD VERIFICATION OF LAND USE INFORMATION

The scale of mapping in CARETS, the size of the region, and the requirement for rapid mapping to obtain current coverage necessitated the development of new techniques of field verification rather than conducting ground surveys. CARETS investigators used such techniques throughout the project to increase interpreter skill by familiarization with ground truth, to field edit CARETS land use maps, to determine the accuracy of such data sets, and to test the usefulness of the CARETS land use classification system. This section documents field checking research during the project and presents the results of such research. The culmination of research involving field techniques, a study of cost-accuracy-consistency comparisons of land use maps made from high-altitude aircraft photography and Landsat imagery, is presented in a separate report and is only briefly discussed here.

### Field Checking in Southeastern Virginia

CARETS researchers conducted initial field checking exercises in southeastern Virginia, including the Norfolk-Portsmouth Standard Metropolitan Statistical Area, where numerous project experiments have been conducted. They established the following goals for the on-site field verification of CARETS land use maps covering the area:

(1) To examine thoroughly in the field areas and point features that were difficult-to-identify and classify, to complete the identification of questionable areas, and to resolve classification problems encountered;

(2) To test sampling procedures designed to examine the error from whatever source;

(3) To investigate classification-category areas to discover the "mix" of noncategory land uses within each designated category area, and to determine the percentage of error resulting from both interpretive errors and the use of the minimum area recording unit (minimum mapping size) as a tool of discriminatory analysis.

With these goals in mind, CARETS investigators designed procedures for a limited on-site field verification experiment. The results of that experiment indicate that the tested procedures could satisfy the above objectives. The field activities in this experiment involved three basic phases: (1) preliminary planning, (2) on-site investigation, and (3) data analysis.

The preliminary planning stage activities included acquiring necessary support materials (manuscript maps supported by road maps, planning commission maps, and 1:24,000-scale USGS topographic sheets) and determining the areas to be checked. Researchers identified the following types of features, noted them on the manuscript maps for location, and outlined them on topographic and road maps:

(1) <u>Special feature areas</u>.--These areas included land parcels identifiable only in the field or possessing unique characteristics presenting classification difficulties. This category also included sites for which photographs and further observations were desirable.

(2) Category areas.--Investigators selected sample areas the size of three-to-five city blocks within the Level II land use boundaries for each category recorded, where observers were to determine the percentage "mix" of noncategory features within each category area. Investigators usually selected sites from the central portion of each category area to avoid the mixture problems associated with boundaries.

(3) Boundary areas.--Investigators designated sample areas of a size similar to the category areas along various sections of Level II land use boundaries for examination of land use "mix" and for verification of boundary correctness. Boundary areas, unlike category areas, were divided into equal-area sections on each side of the boundary line to provide percentage figures that would also reflect the composition of the fringe areas of the examined categories.

(4) Air observation areas.--Investigators designated certain areas for verification by low-altitude aircraft flights because of their relative inaccessibliity. Their identities could be verified most efficiently by air in respect to time and travel costs. In theory, air observation areas could include special feature, category, or boundary areas although in practice researchers would have difficulty mapping the more complex category and boundary areas by this method.

Time limitations encouraged field investigators to obtain a maximum amount of information with a minimum number of site visits. Investigators

planned to visit all accessible special features, and select category areas to obtain a sample of a wide range of types. For example, they visited residential category areas in different economic classes of neighborhoods. They even selected some category and boundary areas because of the difficulty in classifying them.

Because random site selection procedures were not used, the field results have some statistical bias. Investigators believed, however, that the careful selection of known sites, with a limited range of characteristics, rendered the general sample sufficiently typical to make the figures obtained significant descriptors of the interpretation and mapping accuracy for that part of the CARETS region.

Field observation teams consisted of a driver, who also took photographs and notes on the sites, and a navigator, who recorded the pertinent data relating to a site. Investigators obtained special feature, category, and boundary observations by driving to and around a designated area, identifying it, photographing it (if desired), and field mapping its land use to scale in a notebook using the two-digit Level II land use code.

An experiment in air observation proved that observing sites from a low-altitude aircraft can be accomplished in a similar manner, providing the route is carefully planned. Researchers also found that observations from low-altitude aircraft are much more efficient than those from the ground.

The data analysis phase consisted of (1) measuring land use areas with a dot planimeter on the scale drawings completed in the field;

(2) calculating the percentages of the land use mix for each site observed; (3) reassembling these data into order by categories of the classification system; (4) tabulating, weighting, and averaging the percentage data; and (5) completing identification of special areas by entering the correct notation on the manuscript map.

The most common errors include those of interpretation and judgement (classification errors), boundary placement, and incorrect labelling, those resulting from the existence of multiple uses on any one piece of land, and those caused by the time lapse between the date of photography and the date of field verification. Investigators designed the sampling system used in the CARETS field visitation process to examine sample areas (not points) and analyze the working efficiency of individual categories in the classification system. They based the examination on the percentage mix of category and noncategory use found in the sample areas and on the correctness of the boundaries drawn between individual land uses. Although sampling of areas requires greater effort than sampling of points, the findings provide considerably more information relating to the performance of the classification system, the interpreters, and the cartographers.

CARETS investigators devised three distinct steps in approaching the question of the accuracy of sampling areas: (1) determining the percentage mix of each land use category polygon; (2) establishing threshold limits or amounts of mixing allowable to determine the correctness of polygon interpretation; and (3) summarizing the data, comparing them with established threshold values and obtaining an

accuracy statement. One can determine the percentage mix of each land use category polygon by measuring the area of each land use in the sample polygon and computing the percentage of the total area occupied by each land use category. By summarizing the information for all such polygons according to the categories of land use assigned in the interpretation and mapping processes and placing the summary percentage data in matrix format, one can obtain statistics to help analyze the performance of each category in the classification system.

By further ordering the percentage mix data so derived, one can obtain figures that can be interpreted as "accuracy" statements in much the same manner as the conventional dichotomous-sampling figures are interpreted. One can establish a percentage threshold to determine what values are acceptable.

The CARETS field verification teams examined and recorded a total of 371 areas during the initial experiment. Two teams, travelling by automobile, examined and mapped 83 special features, 198 category areas, and 90 boundary areas during 8 days of field work. They mapped all accessible sites and found only seven areas to be inaccessible. Familiarity with procedures, planned driving routes, and the use of notebooks with all areas mapped to scale permitted an average site-mapping time of 2 minutes and an average driving time between sites of 13 minutes.

Tables 8 and 9 summarize the general results of the field observations, in the form of percentage-mix matrices. Table 8 shows category areas in respect to their actual percentage mix of both category and noncategory features as observed in the field. The

Table 8 --Percentage of actual land use occupying mapped land use categories

| Mapped Land Use Category* | Sample Size | Actual Land Use 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 21 | 22 | 41 | 42 | 51 | 52 | 53 | 54 | 61 | 62 | 72 | 74 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 32 | 89.3 | 2.1 | | | 0.2 | 0.2 | | | 3.0 | | | 1.5 | 3.7 | | | | | | | | |
| 12 | 29 | 13.7 | 64.4 | 5.5 | | | 7.0 | | 7.0 | 1.8 | | | 0.6 | | | | | | | | | |
| 13 | 12 | 0.6 | 3.0 | 90.0 | | | | | | 6.4 | | | | | | | | | | | | |
| 14 | 5 | | | | 72.0 | | | | | 20.0 | | | | | | | | | | | 8.0 | |
| 15 | 14 | 1.9 | 1.5 | | | 77.1 | | | | 7.1 | | | 5.2 | 7.2 | | | | | | | | |
| 16 | 18 | 4.4 | 0.4 | | | | 91.2 | 2.2 | | 0.4 | | | | | | | | | | | | 1.4 |
| 17 | 4 | | | | | | | 100 | | | | | | | | | | | | | | |
| 19 | 12 | 5.0 | 2.5 | | | | 0.7 | | | 86.0 | 5.8 | | | | | | | | | | | |
| 21 | 21 | 0.1 | | | | | 0.6 | | | | 79.4 | | 5.8 | 14.3 | | | | | | | | |
| 22 | 2 | 1.5 | | | | | 1.5 | | | | | 47.0 | 50.0 | | | | | | | | | |
| 41 | 14 | 14.6 | | | | 1.1 | | | | 3.6 | | | 78.9 | | | | | | | | 1.8 | |
| 42 | 10 | 1.0 | | | | | | | | 3.0 | 10.0 | | 4.0 | 82.0 | | | | | | | | |
| 52 | 2 | | | | | | | | | | | | | | | 50.0 | 50.0 | | | | | |
| 53 | 6 | | | | | | | | | | | | | | | | 100 | | | | | |
| 54 | 3 | | | | | | | | | | | | | | | | | 93.3 | 6.7 | | | |
| 61 | 9 | | | | | | | | | | | | 6.1 | 1.1 | 1.7 | | | | 85.6 | 5.5 | | |
| 62 | 1 | | | | | | | | | | | | | | | | | | | 85.0 | | 15.0 |
| 72 | 4 | 16.3 | | | | | | | | | | | | | | | | | | | 83.7 | |

*(Land use categories key in table 6)

Table 9 --Percentage of actual land use occupying land use boundary areas

| | | Actual Land Use | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Category Number * | Sample Size | 11 | 12 | 13 | 14 | 15 | 16 | 19 | 21 | 41 | 42 | 61 |
| 11 | 71 | 83.2 | 7.6 | | | | 2.4 | 3.2 | 1.4 | 2.0 | 0.2 | |
| 12 | 37 | 26.1 | 56.7 | 7.9 | | | 3.1 | 5.1 | 0.3 | 0.8 | | |
| 13 | 16 | 9.1 | 20.3 | 58.3 | | | 1.1 | 9.7 | | 1.5 | | |
| 14 | 2 | | | | 100 | | | | | | | |
| 15 | 6 | | | 11.7 | | 88.3 | | | | | | |
| 16 | 19 | 1.3 | | | | | 93.9 | 1.8 | | 3.0 | | |
| 19 | 10 | 6.0 | | | | | | 93.3 | | .7 | | |
| 21 | 10 | | | | | | 3.5 | | 94.8 | 1.7 | | |
| 41 | 7 | 13.6 | 5.0 | | | | 1.0 | 4.0 | | 76.5 | | |
| 42 | 2 | | | | | | | | | | 100 | |
| 61 | 3 | | | | | | | | | | | 100 |

*Land use categories key in table 6

photointerpreted categories are listed on the left, and the field observations are reported in the matrix to the right, according to the percentages of the sample area found to contain the land uses listed along the top of the matrix. The land use category numbers are those listed in the CARETS working version of the land use classification system for use with remote-sensor data (table 6).

A high percentage figure for matching categories in the matrices is an indication of few errors in interpretation or mapping. Category 13 (industrial land), for example, presented few interpretation problems according to the modified working version of the USGS classification system. Ninety percent of the land in the designated sample industrial areas contained industrial land use, with insignificantly small amounts of residential, commercial and urban uses. The percentage for matching categories indicates that individual results for each sample area should be checked thoroughly to determine the cause of the error, whether of poor land use category definition, interpreter error, or error in mapping.

Both the organization and interpretation of table 9 are similar to those of table 8, except that the percentages are recorded separately for each of the two halves of the boundary area, as each may be treated as a category area. Thus, a boundary area between categories 12 and 13 would be recorded in the same manner as one category 12 and one category 13 area would be in table 8 under the separate headings for each category. The total recorded sample sizes are thus twice as large as the number of boundary areas visited. In this manner, information concerning the composition of the fringe sections of the

category areas could be obtained and compared with similar format information from the core of the category areas.

Many of the same problems reappeared in the boundary area matrix presented in table 9. A noticeable difference between the two tables, however, is that the percentages for the noncategory areas appeared to be larger in the boundary areas than in the corresponding category core areas This difference is to be expected in view of the merging that normally takes place in contact zones between concentrations of land use types. Readily apparent in analyzing the causes of the anomalies is the relation between the extreme difficulties in delimiting commercial/residential and commercial/industrial zones and the problems examined above under the table 8 discussion. The other apparent anomalies resulted from single and unique interpretation mistakes.

Another type of statistic gathered from the field-mapping notebooks does not appear in the tables: an interpretation based on the scale drawings, made to determine the boundary correctness for each boundary area visited. For the 92 boundary areas observed, the boundary had been interpreted correctly in 57 cases (62 percent of the time). In 15 cases (16 percent of the time), minor boundary corrections should have been made, and in 20 cases (22 percent of the time) the boundaries were totally incorrect.

The error ratios may be somewhat misleading, as researchers selected many of the boundary areas from positions that were difficult to interpret to allow scrutiny of particular classification problems. In addition, the sampling procedures were not randomized, and at least

some of the boundary errors resulted from incorrect category classifications. Nevertheless, these statistics show the 78 percent of the time the boundary was quite close to where it should have been.

In the field, observation teams visited 198 category areas and, observed sites for all 18 of the categories existing in this section of the CARETS region. The statistics in table 8 reveal the type of category and noncategory mixing resulting from the use of the minimum area recording unit and the problems introduced by the other sources of error.

The appearance of anomalies in this table, in the form of high percentages of noncategory areas present within a particular category, indicate either a weakness in the classification system or an error in interpretation and mapping. Where apparent problems existed, researchers checked the original field notebooks for an explanation. By analyzing the data in this manner, they identified several problem areas. The large mixture of categories present in commercial areas (category 12) suggests that one should make more use of the urban mixed category (category 18), or that the commercial and services category should be redefined. A large amount of open land (category 19) is found in transportation areas (category 15), especially at freeway intersections.

In addition, the field investigation revealed that some of the category area problems could be resolved only by field visits. Many "industrial parks" are primarily commercial rather than industrial, but a correct identification can only be made by visiting the site. Open land and extractive scars must frequently be observed on the

ground to ensure proper identification, as between areas under construction and operating sand or gravel pits.

## Field Checking the Remainder of the CARETS Region

Continuing efforts to field verify the CARETS Level II land use maps, in June 1973 investigators field checked 19 land use sheets covering Delaware, the District of Columbia, Maryland, New Jersey, Pennsylvania, and northern Virginia. Visiting only sites whose identity was questioned by the interpreters, CARETS investigators found that the interpreters had correctly identified 52 percent of the sites or 174 out of 336 sites visited. Field investigators also found that the land use in 16 sites (4.8 percent of total sites) had changed between 1970 and 1973.

As in the field checking in southeastern Virginia, two-man teams checked the sites, one person driving and the other navigating and recording. When the team approached a site, the recorder filled in the appropriate information on a field editing worksheet (table 10) and sketched the site in a field notebook.

The percentage of correctly interpreted land use varied considerably by land use category. Table 11 identifies the percentages of correct land use for problem areas and shows that problems existed in rural and urban areas.

## Accuracy Investigations from Helicopter

To establish map accuracy sampling techniques and procedures, CARETS investigators field checked portions of the Eastern Shore of Virginia and Maryland by helicopter. In previous research, investigators

Table 10

FIELD EDITING WORKSHEET

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Office | Sheet No. | | | | | | | | | | | | | | |
| | Polygon No. | | | | | | | | | | | | | | |
| | Area (Hectares) | | | | | | | | | | | | | | |
| | Level I ID. | | | | | | | | | | | | | | |
| | Level II ID. | | | | | | | | | | | | | | |
| | Photo Interpretation Problems | | | | | | | | | | | | | | |
| | 1970 - 1973 Change | | | | | | | | | | | | | | |
| Field | Level II ID. | | | | | | | | | | | | | | |
| | Level III ID. | | | | | | | | | | | | | | |
| | Field Observ. Comments (Min. Size, etc.) | | | | | | | | | | | | | | |
| | Indication of Recent Change | | | | | | | | | | | | | | |
| | Photo Exposure | | | | | | | | | | | | | | |
| Office | Map Corrected Polygon (s) | | | | | | | | | | | | | | |
| | Change Master Map: Remained Single Polygon | | | | | | | | | | | | | | |
| | Change Master Map: Became more than one Polygon | | | | | | | | | | | | | | |
| | Change Master Map: Combined with other Polygons | | | | | | | | | | | | | | |

Table 11--Percentage of correct land use interpretation of problem areas

| Land use category* | Percentage of hectares interpreted correctly |
|---|---|
| 11 | 69 |
| 12 | 33 |
| 13 | 73 |
| 14 | 22 |
| 15 | 41 |
| 16 | 66 |
| 17 | 13 |
| 18 | 100 |
| 19 | 23 |
| 21 | 5 |
| 22 | 21 |
| 23 | 6 |
| 24 | 0 |
| 41 | 100 |
| 42 | 21 |
| 61 | 100 |
| 62 | 100 |
| 72 | 20 |

* See table 6 for land use categories used

partitioned the CARETS region into 12 zones on the basis of similarity of tones and textures on a Landsat black and white uncontrolled mosaic. These zones, called photomorphic regions, (figure 16) were assumed to be indicative of a polygon density relationship. Investigators selected these photomorphic regions as boundary discriminators for sampling.

In choosing points for sampling, investigators used a stratified systematic unalined sample consisting of 36 points for each of the three photomorphic regions involved (regions II, IV, and VI). They obtained the sample points by placing a dot pattern of 36 equally spaced dots over a 1:250,000-scale gridded and rectified high-altitude aircraft photography mosaic with photomorphic delineations. Because the photomorphic regions are assumed to be homogeneous throughout, the dot patterns may be placed in any part of each region. Researchers therefore placed the dot pattern to minimize region-to-region travel time and keep the experiment in a more workable time and area frame. Investigators then transferred the sample points from the 1:250,000 photomosaics to 1:100,000 photomosaics, which markedly facilitated locating and identifying sample points.

Working in conjunction with NASA, CARETS researchers obtained the use of a UH1B helicopter based at Wallops Station, Virginia. As part of mission planning, investigators drew flight lines from point to point on the 1:100,000 scale photomosaic and the flight azimuth over each segment or leg to give the pilot a magnetic heading for guidance to the next point. One investigator navigated, while the other recorded the land use at each point and photographed each point with two cameras, one containing color film and the other color-infrared film.

# CARETS PHOTOMORPHIC REGIONS

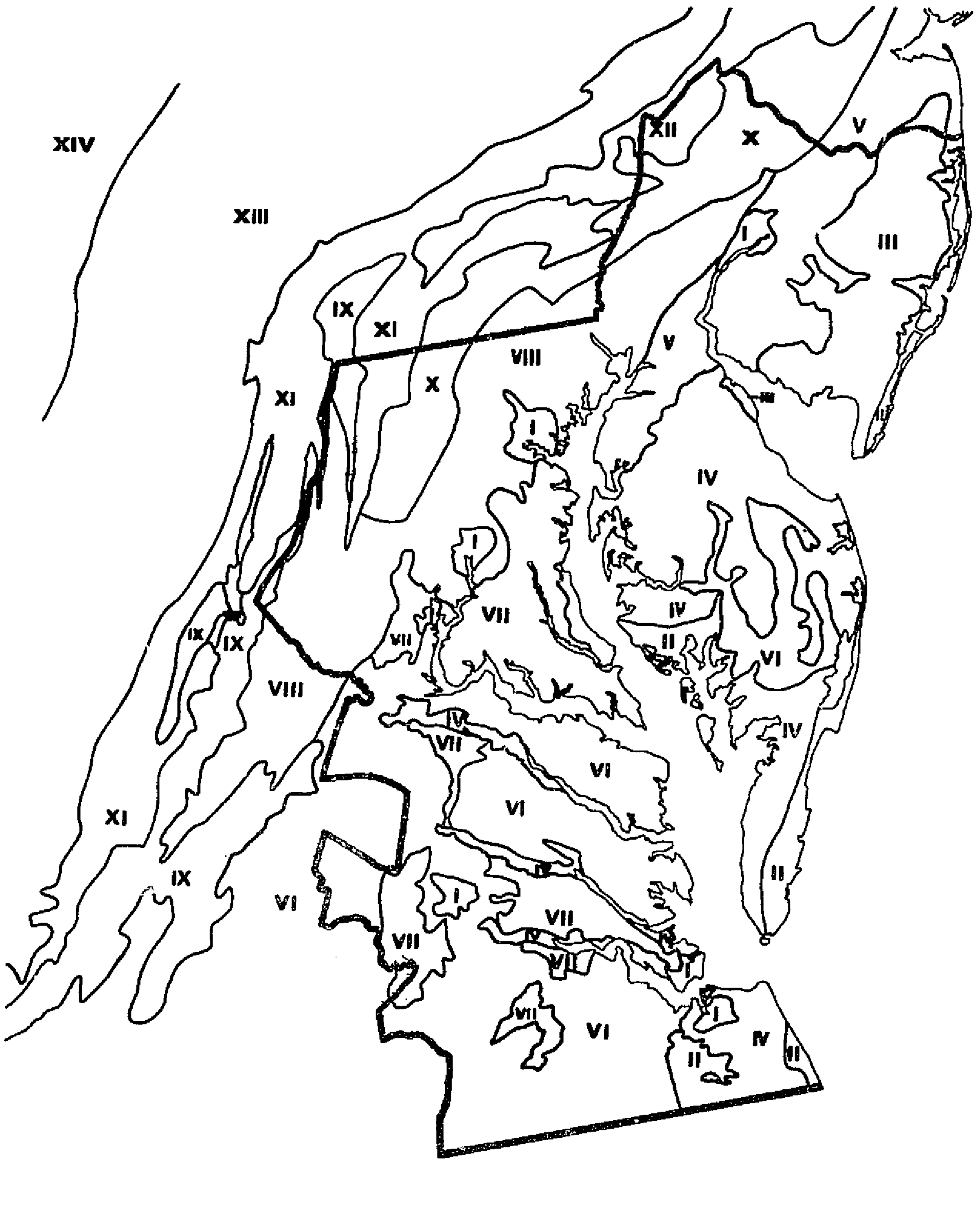



Figure 16.

Accuracy percentages for sites in the photomorphic regions are presented below:

| Photomorphic Region | Accuracy Percentage |
|---|---|
| II | 100.0 |
| IV | 94.5 |
| VI | 97.2 |

One must recognize, however, that the three photomorphic regions sampled are predominantly rural and have relatively simple land use patterns compared to more complex conditions elsewhere in the CARETS region. The degree of accuracy displayed in these regions, therefore, should not be mistakenly assumed to be consistent with those in the other CARETS photomorphic regions.

## Systematic Sampling for Accuracy

CARETS investigators undertook their most comprehensive accuracy study using a stratified random sampling technique to select and obtain a variety of accuracy measurements. They used a 1-percent sample of the entire CARETS region, including 28, 5 X 5-km sample sites in nonurban areas and 15, 2 X 2-km sample sites from within urbanized areas as defined by the Bureau of the Census. The stratification into urban and nonurban categories resulted from the earlier studies that suggested different accuracy problems with the two kinds of areas.

CARETS investigators assessed the effect of generalization to smaller map scales using land use maps comipled at 1:24,000, 1:100,000, and 1:250,000, from the same remote sensing source (high-altitude aircraft photography), and field verification by ground or low-altitude aircraft observation or both. Preliminary results indicated lower accuracies than expected for a point-by-point comparison using a 1-km sample grid overlay on all the sample sites.

Accuracy of Land Use Classification at Sample Points for Three Scales Using Same Source Material

| Scale | Accuracy |
|---|---|
| 1:24,000 | 85% |
| 1:100,000 | 77% |
| 1:250,000 | 73% |

The above figures obscure the dependency of accuracy of the types of land use--the Level I categories at the three test scales.

Comparison of Accuracy of Level I Interpretations at Three Scales

| Scale | Level I Category, Percent Correct Identification | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 4 | 5 | 6 |
| 1:24,000 | 79 | 88 | 91 | 98 | 72 |
| 1:100,000 | 80 | 83 | 83 | 88 | 67 |
| 1:250,000 | 69 | 75 | 79 | 78 | 72 |

Investigators also compared samples derived from Level I interpretations of Landsat imagery and Level I interpretations of high-altitude aircraft imagery at the same scale. They identified the Level I land use at the center points of each 1-km cell within each sample site on the Landsat and aircraft-derived maps and found the Landsat maps to have an overall accuracy of 70 percent as compared to the 77 percent accuracy for the maps from high-altitude photography at a scale of 1:250,000. The major land use types in discrepancy between the two maps were found to be in the urban and built-up area (category 1). The following table illustrates accuracy as a function of Level I land use categories:

Comparison of Accuracy of Landsat and Aircraft Interpretation
Level I Point Sample

| | Level I Categories, Percent Correct | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 4 | 5 | 6 |
| Aircraft | 69 | 75 | 79 | 78 | 72 |
| Landsat | 34 | 67 | 77 | 82 | 61 |

## HIGH-ALTITUDE AIRCRAFT PHOTOGRAPHY CHANGE DETECTION

The accurate detection of change from high-altitude aircraft photography involves a very tedious process that is still in a developmental stage. The method of detecting land use change for the CARETS region consisted primarily of comparing the 1972 photography of an area with the 1970 photomosaic of the same area overlaid by the 1970 land use map. Any gross differences detected are likely to be real changes. Although this method may be efficient for rural areas where changes are few, it appears to be insufficent for urban or dynamic areas where change is great and may be subtle as well as obvious. Because of these problems, this section will summarize the land use change detection procedures for urbanized areas developed by the USGS Geographic Applications Program's Census Cities project as they would apply to CARETS land use change between 1970 and 1972. Though highly time consuming, these procedures seem to comprise the most accurate manual method available and are particularly apt for change detection in urban areas.

Before conducting a change detection study, interpreters must prepare necessary photography and materials. Photography for the two different time periods is required along with the photomosaic mapping bases and land use transparencies covering the area to be examined. Also necessary are 1-km$^2$ grid templates on positive film transparencies at the same scale as the photography (1:120,000). The grid template serves as the basic unit of observation, enabling a block by block comparison.

The 1-km$^2$ grids should be positioned on the 1970 and 1972 film transparencies so that two or more grid cells enclose an area common to that enclosed by grid cells on the 1970 mosaic. Then, using a hand lens, the interpreter should compare areas of land use within each grid cell between the 1970 and 1972 photographs. The land use overlays should first be checked with the 1970 photography to ensure agreement between the two. Then valid changes in land use categories should be identified either by superposition of photography (1970 over 1972) if scales are similar, or by juxtaposition. Several classes of change can be identified:

(1) change within a land use area from that use to another;

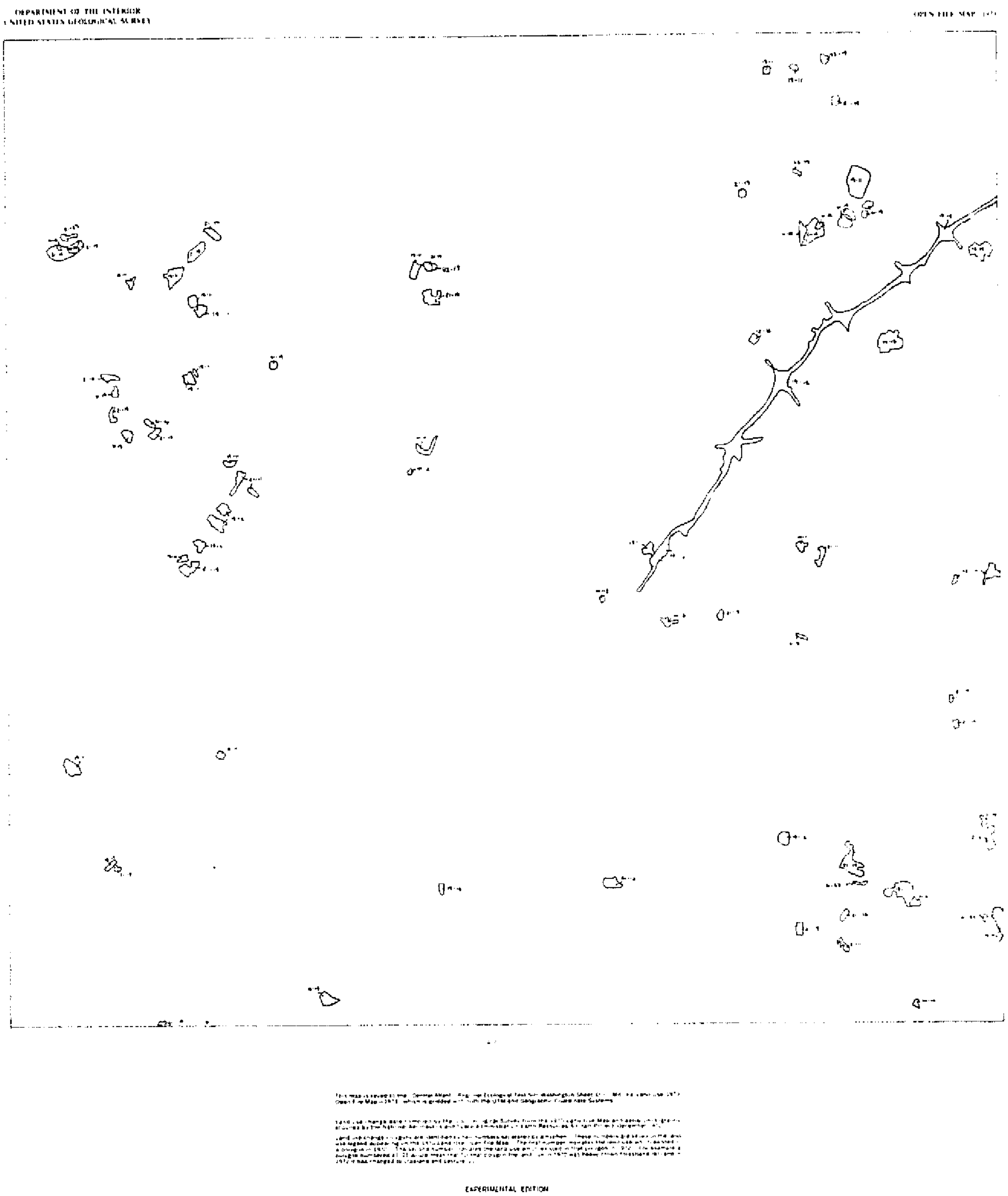
(2) change in or at land use boundaries;

(3) change in category involving no boundary changes (may result from original misclassification); and

(4) change in land use due to omission not mapped originally.

One should exercise caution when identifying areas of land use change to insure that possible differences in appearance or signature of the same feature at two different times are not identified as changes. This possibility may result from differences in the time of year, sun angle, quality of photography, and scale of the photography.

Land use change boundaries should first be marked on the older photography overlay. Changes may be noted by making the former land use digits first, followed by a dash and the digits of the new land use of the new land use. Thus a polygon or area marked by a 21-11 has changed from cropland or pasture to urban residential. Once all changes have been identified and marked on the photography overlay, they should be carefully transferred to an overlay registered to the photomosaic and 1970 land use overlays. Figure 17 presents a reduced specimen of a CARETS Level II 1970-72 land use change map.




LAND USE CHANGE MAP, 1970–72, WASHINGTON SHEET, D.C., MD., VA.
1973

Figure 17.

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OF POOR QUALITY

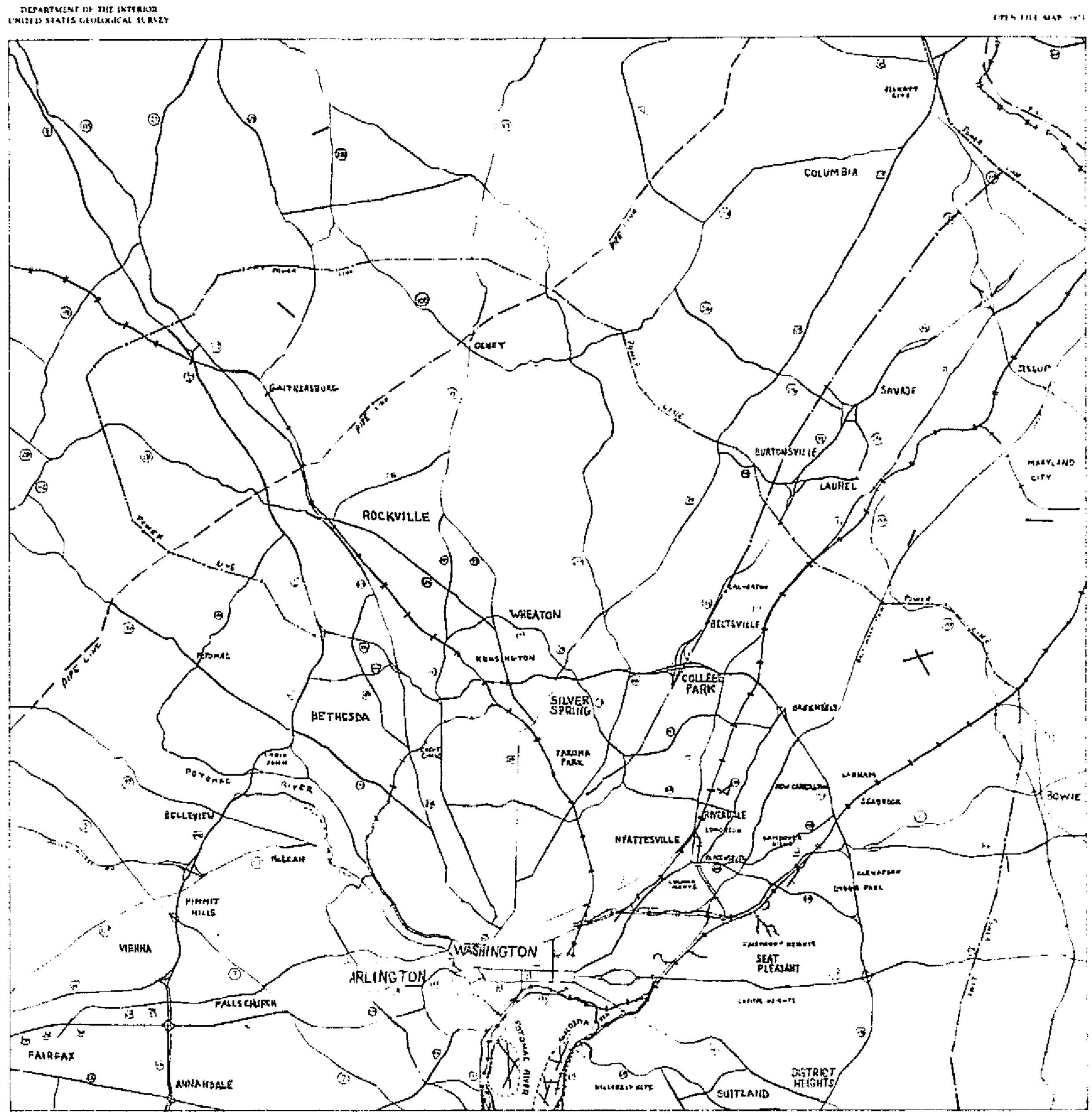
## COMPILATION OF OTHER OVERLAYS

To facilitate the use of and increase the value of land use maps derived from high-altitude aircraft photography, the CARETS project produced a series of overlay sheets, keyed to the 1:100,000-scale photomosaics. Project investigators designed these sheets for use as film transparencies for visual presentation and for conversion to digital form for the spatial grouping of the land use data. With a computer overlay capability, investigators will be able to obtain land use data for any part of the test site delimited on an overlay.

In compiling the various overlay sheets, CARETS researchers transferred data from source materials to pieces of drafting film overlying the photomosaics, using similar procedures to the original 1970 land use compilation and the change detection study. The photomosaics were of great value for producing the overlays.

The project prepared cultural feature overlays, county boundary and census tract overlays, drainage basin overlays, and landform and surficial materials overlays. Specimen samples of such overlays for the Washington, D. C. sheet are presented in figures 18 through 21.

The need to locate specific areas on land use maps led to the compilation of a series of cultural features maps. Compiled primarily from USGS 1:250,000-scale topographic sheets, these overlays show place names and such transportation facilities and lines as airports, railways, highways, pipelines, and power transmission lines. Such maps are often referred to as "point and line" maps because they provide point and line

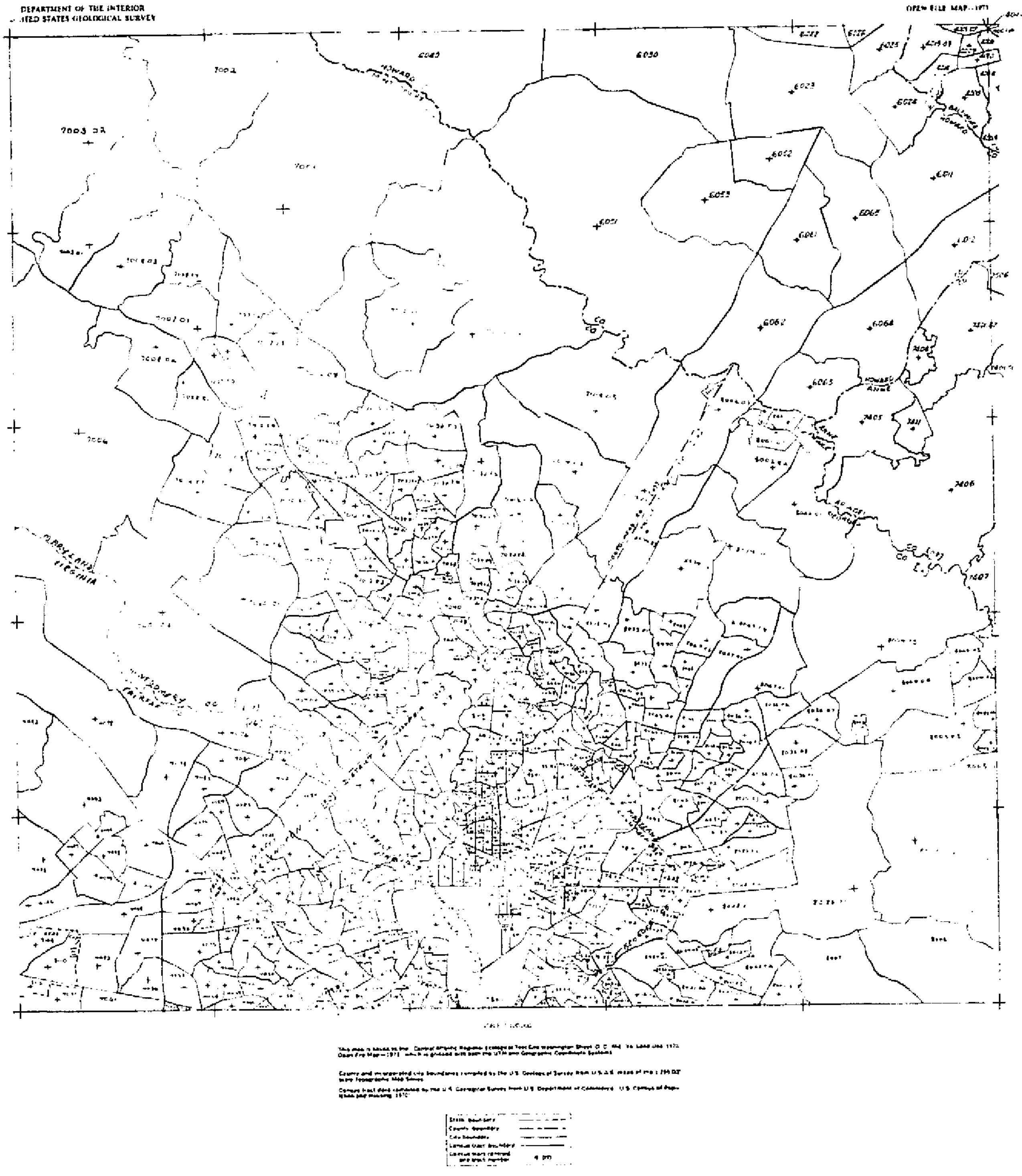



EXPERIMENTAL EDITION

CULTURAL FEATURES MAP, 1970, WASHINGTON SHEET, D.C., MD., VA.
1973

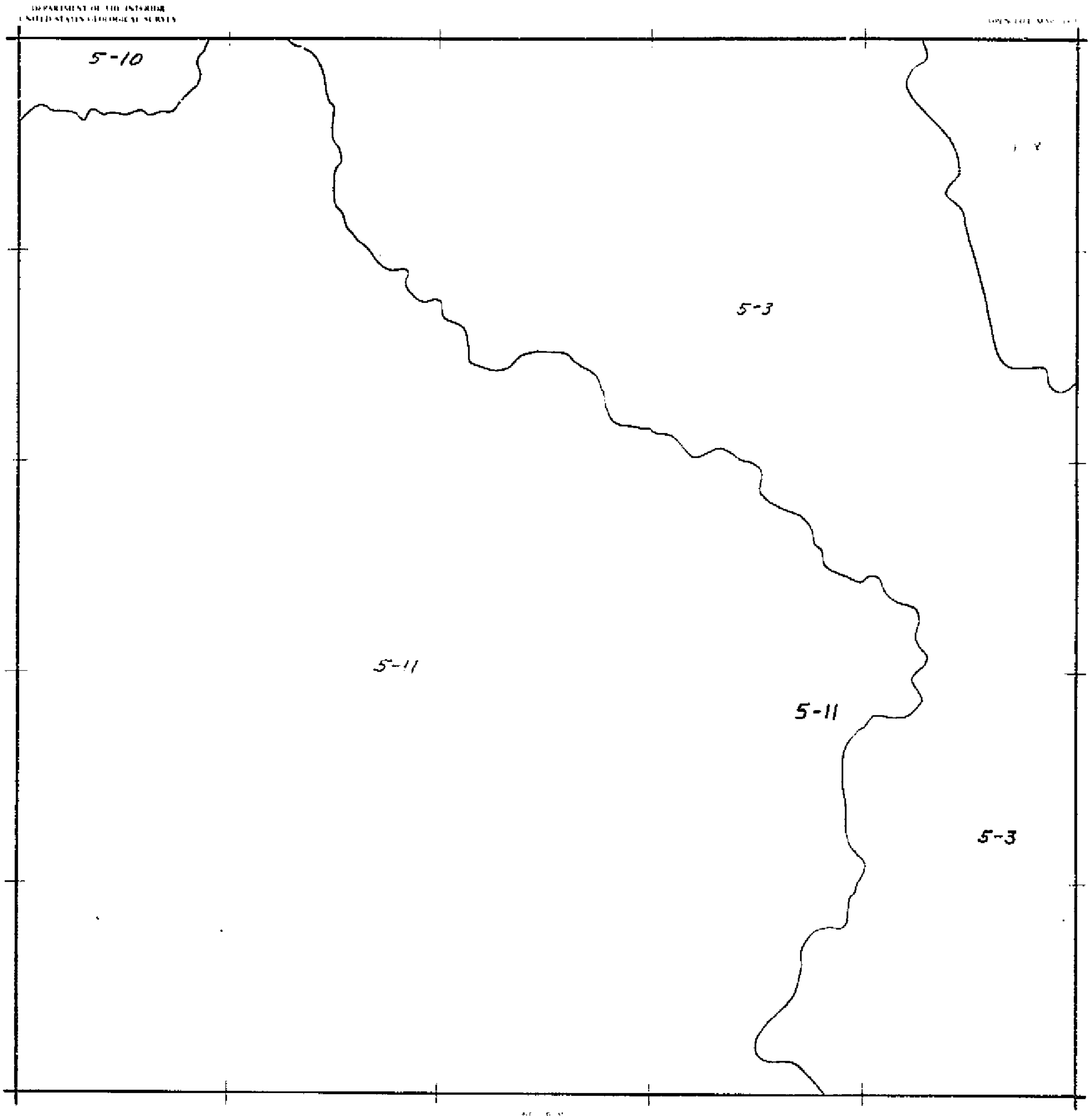
Figure 18.

ORIGINAL PAGE IS
OF POOR QUALITY




COUNTY BOUNDARY AND CENSUS TRACT MAP, 1970, WASHINGTON SHEET, D. C., MD., VA.
1973

Figure 19.




DRAINAGE BASIN MAP, 1970, WASHINGTON SHEET, D. C., MD., VA.
1973

Figure 20.

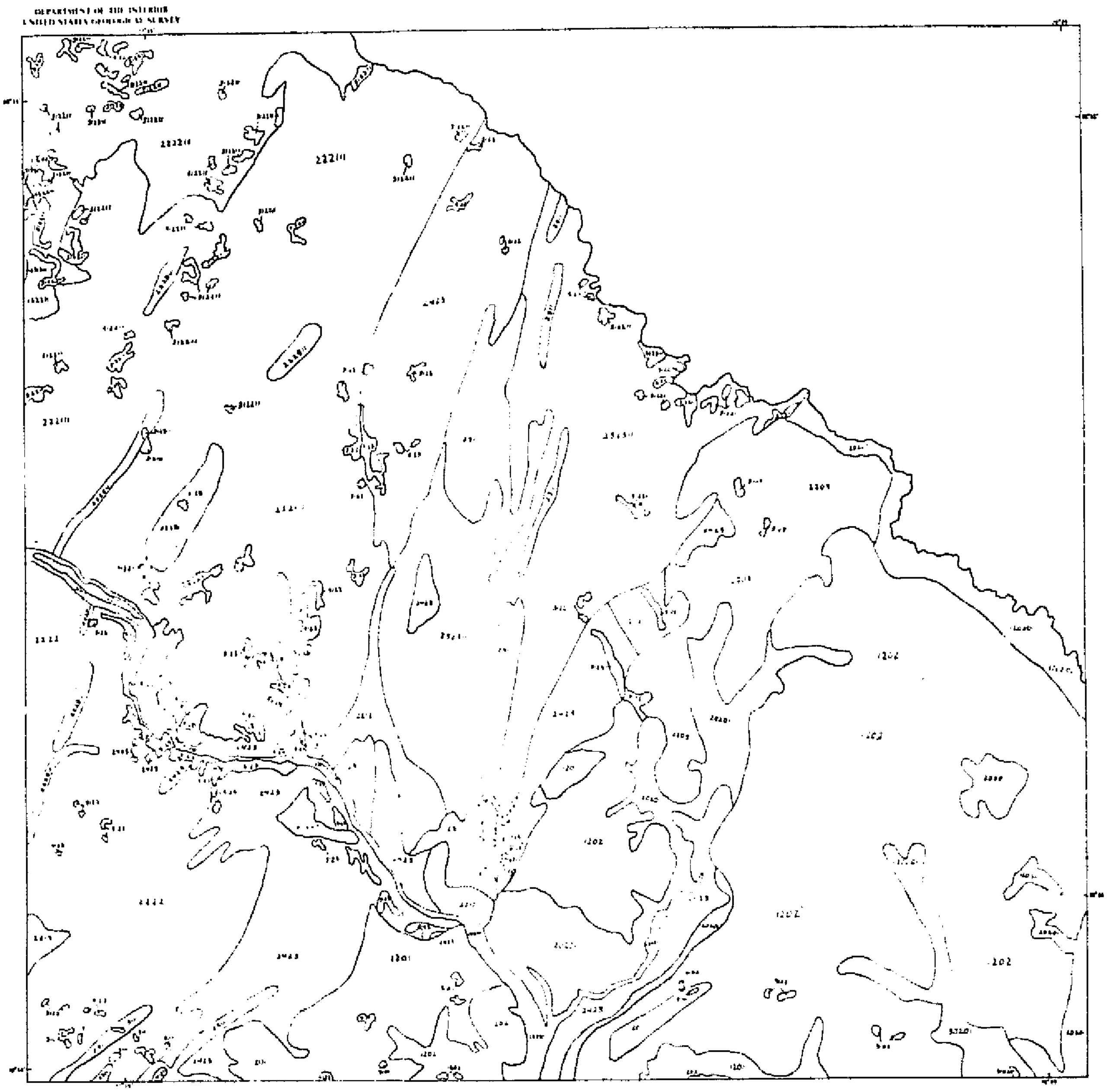


Figure 21 --Landforms and surface materials map, Washington Sheet, D.C., Md., Va.

Reduced from 1:100,000 scale

Reduction of specimen sheet of landforms and surface materials map, Washington D.C., Md., Va., Sheet. Prepared as overlay to photomosaic (figure 3). Key to numbered categories is presented in table 12.

references that are prominent on the source photography and on the ground and are significant to an area's surrounding land use (figure 18).

CARETS investigators designed the cultural features maps to provide locational cues for users of the land use and other data sets rather than for conversion to digital form.

Another regional data set for which the CARETS project desired land use comparisons was the location and boundaries of geographic areas used by the Bureau of the Census for reporting population statistics. For all Standard Metropolitan Statistical Areas (SMSA's) within the test site, the project compiled census tract maps keyed to the 1:100,000-scale photomosaics. For portions of the test region not inside SMSA's, the project prepared sheets showing the location of county boundaries (figure 19).

The basic source data for the compilation of census tract and county boundary maps include census tract maps published with the SMSA census tract data of the Census of Population and Housing. Also necessary were city and county maps and USGS topographic maps, identifying the features that delimit census tracts and county boundaries on the ground and thus facilitating the transfer of political boundaries onto the overlays.

To allow the association of land use information with drainage basins, the CARETS project compiled a set of major drainage basin maps for the region (figure 20). Data for these maps were obtained from the USGS Office of Water Data Coordination (1972). The drainage basin boundaries were drawn over the photomosaic base, and topographic maps were used as supplementary source material.

Finally, to test the usefulness of surficial geological information in association with land use data, researchers prepared a set of maps depicting landforms and surface materials for the Washington, D.C. and Norfolk-Portsmouth SMSA's and for five additional sheets in southeastern Virginia (figure 21). The basic source data for such maps consist of U.S. Department of Agriculture soil surveys and other soils maps, as well as geologic and topographic maps. The landform and surficial material maps were designed to assist in relating land use to relevant surficial conditions such as the engineering characteristics of near-surface materials, information CARETS investigators expected would aid planners in identifying the characteristics most suitable from a geologic and hydrologic standpoint for future development of various land use types. The classification scheme used for the landforms and surficial materials overlays is presented in table 12.

Further information on the preparation of overlays for land use maps, including land ownership overlays not prepared for CARETS, is available in Wiedel and Kleckner(1974).

Table 12--Landforms and surface materials classification legend

**LANDFORMS-Digits 1 and 2**

| | | |
|---|---|---|
| No Slope, No Relief | Water | 00 |
| | Marsh, swamp | 01 |
| | Bogs | 02 |
| | Beaches | 03 |
| Little Slope, Small Relief | Flats, undissected | 11 |
| | Flats, dissected | 12 |
| | Flood plains | 13 |
| | Terraces | 14 |
| Gentle to Steep Slope, Moderate Relief | Sand dunes | 21 |
| | Hills | 22 |
| | Low Ridges | 23 |
| | Valley sides | 24 |
| | Gulley sides | 25 |
| Steep Slope, High Relief | Ridges | 31 |
| Negative Relief | Sinkholes | 62 |
| | Crater lands | 64 |
| | Vertical pits | 66 |
| Man-Made Features | Made land (fill) | 81 |
| | Sanitary landfill | 82 |
| | Waste (mine) | 83 |
| | Quarries, pits | 84 |
| Miscellaneous | Mined-out areas | 91 |
| | Unstable slopes | 92 |

**LITHOGRAPHY-Digits 3 and 4**
(Bedrock more than 9 feet below the surface)

| | | |
|---|---|---|
| Unconsolidated Deposits | Water | 00 |
| | Clay, silt | 01 |
| | Sand | 02 |
| | Gravel | 03 |
| | Boulders | 04 |
| | Colluvium | 05 |
| | Talus | 06 |
| | Organic | 07 |
| Igneous Rocks | Granite | 11 |
| | Gabbro, diorite | 12 |
| | Basalt, diabase, felsite, rhyolite | 13 |
| Metamorphic Rocks | Phylitte | 21 |
| | Schist | 22 |
| | Gneiss | 23 |
| | Quartzite | 24 |
| | Metabasalt | 25 |
| | Marble | 26 |
| | Slate | 27 |
| | Serpentine | 28 |
| Sedimentary Rocks | Shale, siltstone, mudstone | 30 |
| | Sandstone | 31 |
| | Conglomerate | 32 |
| | Limestone, dolomite | 35 |

**MISCELLANEOUS DESCRIPTORS-Digits 5 and 6**

| | |
|---|---|
| High water table | 01 |
| Shallow soil (bedrock less than 9 feet below surface) | 11 |

## LAND USE MAPPING USING LANDSAT IMAGERY

Interpretation of land use from Landsat imagery involved many of the same problems encountered using high-altitude aircraft photography. Investigators had to select a mapping base, devise methods for compilation, learn how to interpret from the imagery, and determine the best format of imagery to use and the format for the final map product. They also had to choose the level of generalization or detail to be mapped and the source materials to be used.

Because the mapping from Landsat imagery was an experiment, investigators wanted to rely as heavily as possible on the imagery and to use only 1:250,000-scale topographic maps as supplementary source data. That CARETS interpreters were familiar with the test site facilitated their interpretation.

Investigators also decided to map as much detail as possible. Although the Landsat-derived maps are generalized Level I interpretations, they also include 19 greater detailed Level II categories and even 4 highly detailed Level III categories where interpreters could identify them. Figure 22 presents a reduced sample of one of these Landsat-derived land use maps.

Landsat imagery is available in several formats, and like high-altitude aircraft photography, its quality varies depending upon atmospheric conditions, season, and processing. CARETS interpreters found that the best form of imagery for land use mapping is the color infrared composite transparency. Such color transparencies or prints are expensive relative to black and white imagery but not relative to the time spent by interpreters. Nevertheless, this report will also provide aids for land use mapping using the less expensive formats.

CARETS interpreters used the following images for their mapping:

E-1045-15243, 6 September 1972
E-1045-15245, 6 September 1972
E-1045-15252, 6 September 1972

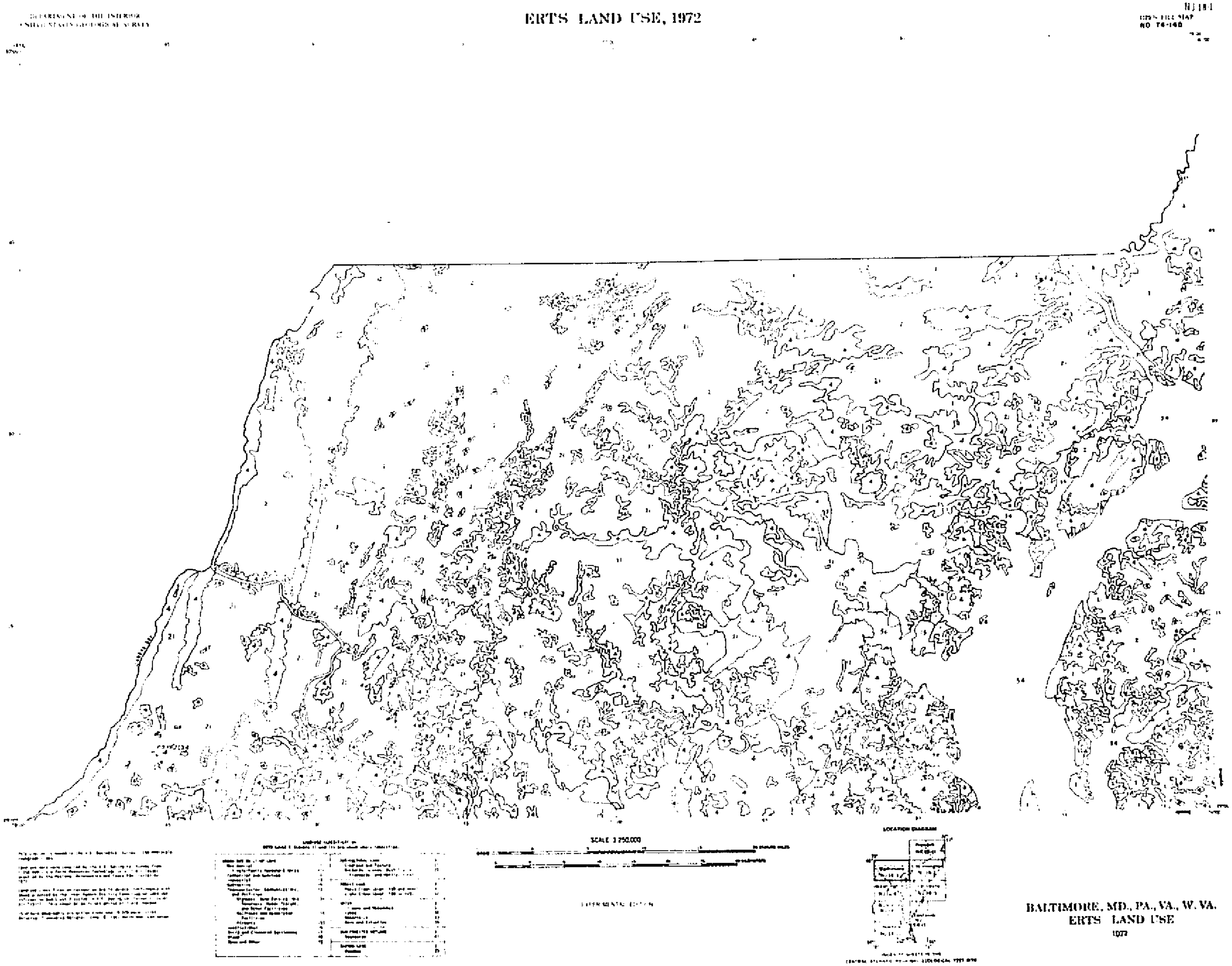

ERTS LAND USE, 1972
SCALE 1:250,000
BALTIMORE, MD., PA., VA., W. VA.
ERTS LAND USE
1972

Figure 22.

E-1079-15131, 10 October 1972
E-1079-15133, 10 October 1972
E-1080-15185, 11 October 1972
E-1080-15192, 11 October 1972
E-1080-15194, 11 October 1972
E-1133-15144, 3 December 1972

Figure 1 and table 1 identify the area covered by each frame.

In preparing overlays for the mapping of the CARETS region from Landsat data, researchers used the format of the USGS 1:250,000-scale topographic sheets, slightly modified by attaching the CARETS portions of the Charlottesville and Roanoke sheets to the Washington and Richmond sheets (figure 23). Interpreters then traced the margins of the overlay sheets directly from the topographic maps onto appropriate sized sheets of frosted drafting film.

Before registering the drafting film to a Landsat transparency, interpreters placed the transparency (in half-frame format) in a transparent protective sleeve and used register pins to hold the transparency immobile. To register the overlay to the Landsat transparency, they placed the transparency on a light table over a topographic sheet of the area to be mapped. They registered the Landsat transparency and the topographic maps as closely as possible and then taped the transparency to the map. They then registered the overlay's margins to those of the map and taped the overlay to the Landsat transparency. With the overlay secure on the transparency, they removed the topographic map and the overlay was ready for use in compilation.

Since at least two or more Landsat half-frame transparencies are needed to map the area of a topographic sheet, interpreters repeated the registration process for every change in transparency. Numerous

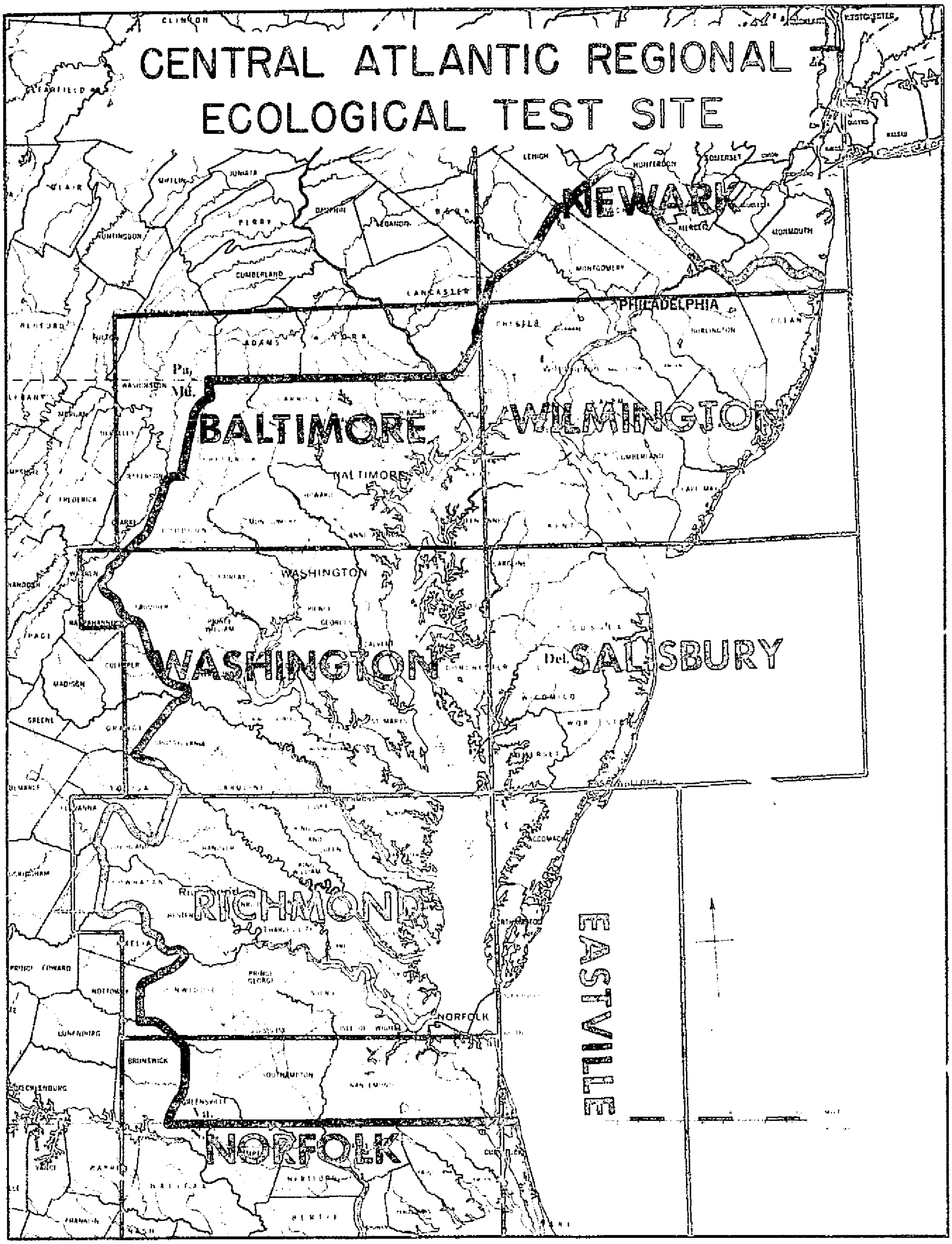



Figure 23--Index to 8 sheets for CARETS 1:250,000-scale data base.

sharp boundaries between land and water in the CARETS region facilitated the registration. In areas where such boundaries do not exist, registration may be more difficult.

The manual interpretation of land use from Landsat imagery consists primarily of identifying land use areas on the transparency and marking on an overlay the boundaries between differing land uses. This often entails the separation of different spectral signatures, identification of specific features by shape or size, or the determination of the land use characterized by a specific texture or pattern. In interpreting Landsat images in the form of color composite transparencies, some features or land use are readily identifiable, whereas others may be interpreted more easily with a knowledge of the area being mapped.

The quality of photographically processed Landsat color composites is not always uniform. The color of the same kind of land use may vary from one transparency to another or from one processing to another.

Water bodies and forests are perhaps the most easily ident iable land uses. Water bodies appear black or a shade of blue when affected by sedimentation. Forest areas appear as dark shades of red. Lighter shades of red indicate other vegetated areas, wetland, agricultural, or urban.

Urban land generally may be identified by light to dark bluish-gray tones and by linear patterns indicating streets and roads. Large, often geometrical areas of red surrounded by urban signatures may indicate parkland, cemeteries, or other open urban land. Areas of black or dark blue in urban areas are likely to represent extremely heavy

concentrations of buildings, areas of heavy industry, or railroad yards. The size, shape, and location of such "black" areas may aid in their identification. Shore linear features extending out into the water indicate the presence of docks, piers, and nearby warehouses. Commercial strips appear as blue-gray linear patterns, with commercial nodes at their intersections.

Because of their great diversity, residential urban areas are represented by numerous different spectral signatures. High density residential areas in the central city appear dark blue and are indistinguishable from surrounding commercial and industrial areas. Less densely populated residential areas appear as blue mixed with red and white Large tracts of single family residences have distinctive signatures, which under some processing appear to be a light, grainy beige. These areas are similar in color to agricultural land but differ by being too large and unbroken by forests to represent field patterns in CARETS. Older and more heavily wooded residential areas are often difficult to distinguish from forest land. Distinguishing between suburban and adjacent agricultural lands is also difficult.

Agricultural land in CARETS may appear as any combination of colors, most commonly white, gray, pink, brown, and red. Most CARETS rural land not in forest is in agriculture; such land is best identified by field shapes and patterns.

CARETS nonforested wetlands, most commonly occurring in coastal lands and on flood plains, appear on a Landsat color composite as muted purple or brown, depending on the processing. Often such wetlands are

penetrated by numerous winding streams. Tidal marshes present the problem of being inundated during high tides but are more easily detectable during low tides.

Barren land is often hard to differentiate from agricultural land, extractive lands, or land under construction but is easiest to recognize as a distinct white signature. Sand beaches are easily detectable as narrow white strips along the coast.

Many of the features identified on Landsat imagery, such as railroad yards, airports, highways, and single-family residential areas, are Level III categories but cannot be interpreted with any degree of regularity.

Black and white enlargements are easier to produce and much less expensive but are more difficult to work with and present problems that color images do not.

Interpreting Landsat imagery using black and white prints at a scale of 1:250,000 may be facilitated by comparing prints from two different bands, preferably bands 5 and 7. Band 5 is sensitive to the longer wavelengths (red) of the visible spectrum, between .6μ and .7μ. Black and white prints of band 5 provide the greatest contrast between forest and cleared land and the greatest resolution in urban land use. Band 7, sensitive to wavelengths between .8μ and 1.1μ in the near infrared, is beneficial for enhancing water areas, and penetrating atmospheric haze and pollution. Wetlands are difficult to resolve using an individual print of either band but may be distinguished by comparing both bands.

Imagery of the same area from two different seasons also facilitates interpretation. Features that blend together in one season may easily

stand out in the next. Recently harvested and plowed agricultural fields contrast strongly with forest areas in the fall but reflect radiation of similar wavelengths to forests in the summer. Winter imagery showing snow cover facilitates identifying cleared land. Identification of wetland areas from Landsat imagery varies in difficulty depending on season, moisture, and temperatures. Wetlands can be most easily mapped by comparing prints from three or four different seasons.

Seasonal tone differences are subject to discrepancies caused by variations in photo processing and daily atmospheric conditions. Therefore, one should compare several Landsat images for any interpretation, and no single signature should be ascribed to a single land use.

Table 13 presents a breakdown of Level I classifications and resulting signatures for black and white enlargements.

For the best interpretations in a single season, fall imagery provides the greatest resolution for spectral bands 5 and 7. The atmospheric conditions at the time of the Landsat pass and the quality of the reproduction, however, affect significantly the useability of Landsat imagery.

Table 13--Image signatures, by land use category for Landsat visible and near infrared black-and-white imagery

| Land Use | BAND 5 | | BAND 7 | |
|---|---|---|---|---|
| | Signatures | season | Signatures | season |
| URBAN | medium to dark gray center city only Road patterns | fall (Oct.) | light gray linearity or solidity to pattern | fall (Oct.) |
| AGRICULTURE | very light gray, drainage field patterns | fall | very light gray white, field drainage patterns | winter |
| FOREST | dark gray or medium gray | winter | dark gray | winter |
| WATER | medium gray variates to light gray near shore | all | dark gray to black solid | all |
| WETLAND | lack of drainages gray-w/standing water | winter | dark gray black | all |
| BARREN LAND | white | all | light gray | all |

## CHANGE DETECTION PROCEDURES USING LANDSAT IMAGERY

CARETS investigators used October and December imagery to test the applicability of Landsat imagery for detecting land use change and to provide a prototype for a change detection study for all of CARETS. The basic procedure involved overlaying a 1970 land use map on a 1972, 1:100,000-scale color infrared Landsat transparency covering the Norfolk area. Areas appearing to have changed were then mapped on drafting film overlaying a photomosaic of the same area. The interpreters used 1970 and 1972 high-altitude photography of the area to verify the detected change.

First, interpreters compared the Landsat image and the 1970 Level II land use overlay to discover unexpected hues and tones, indicating areas that might have changed. If a possible change were noted, the interpreter determined the nature of the change and the classification Level (I, II, III) to which it could be discriminated. He then compared the 1970 and 1972 photography to verify the change and the correctness of the interpretation. The interpreter marked with a black pencil on the second overlay using established CARETS mapping proceudres. "False" changes, suggested by the imagery but not actually occurring, were mapped on the same overlay with an orange pencil. Interpreters gave all of the land use polygons identification numbers and prepared "from-to" change maps for 1970-72 at Level I and II. They also noted Level I and II change areas that could not be identified on Landsat images without recourse to supplementary high-altitude aerial photography. They then measured the change areas by dot planimeter and summarized them in appropriate categories.

Some of the observations regarding Landsat imagery as a tool for change detection are listed below:

(1) Areas undergoing heavy construction are identifiable to Level III. The use of spring imagery will reveal if these areas are plowed fields.

(2) On the October and December imagery, many of the agricultural fields (probably stubble) reflected a blue-gray spectral response similar to that of inhabited urban areas and accounted overwhelmingly for the false changes mapped. These problems may be "seasonal" and may be resolved with early summer imagery.

(3) Older residential areas with heavy tree cover appear on Landsat images as forest.

(4) At Level II, institutional, commercial and industrial categories cannot be distinguished on Landsat images.

(5) Many urban changes are difficult to observe unless the land is disturbed at the time of the imaging. For example, some urban renewal projects were started and completed in the 2-year time span, and although the change was slightly noticeable on Landsat imagery, it would not have been mapped without the attendant aircraft photography.

(6) A square masking device 25 $cm^2$ is useful in interpreting changes.

(7) All category 19 (urban open and other) areas should be checked for completion of construction changes at the later date as a matter of course, since detecting the completion of construction is more difficult than detecting the start of construction.

Using Landsat and aircraft data to detect land use change between 1970 and 1972, CARETS researchers found that the total change from one Level I category to another in the Norfolk test site amounted to 2,924 ha. This figure compares favorably with the rate of change detected for the years 1959-1970 from aerial photography. Comparable summaries for change between Level II land use categories were not available for the earlier period, but from 1970-1972 such change amounted to 3,216 ha. Of the 2,924 ha of change, 90.7 percent was identifiable on the Landsat imagery.

Further analysis of the statistical summaries reveals that 700 ha of land use change were detected from the Landsat imagery at Level I only, and 1,952 ha of change were detected from the imagery at both Levels I and II. An additional 292 ha of Level II change occurring within but not between Level I categories were detected at Level II. Interpreters also detected from the Landsat imagery 616 ha of land use change whose precise nature could not be identified without reference to supplementary high-altitude aircraft photography.

Interpreters were successful using Landsat imagery for detecting the following changes:

Level I - forest to agriculture (4-2)

Level I - agriculture to urban (2-1)

Level I - forest to agriculture (4-1)

Level II - cropland and pasture to residential (21-11)

Level II - cropland and pasture to urban open and other (21-19)

Level II - heavy crown cover forest to residential (41-11)

Level II - heavy crown cover forest to urban open and other (41-19)

Many changes from urban open to residential, however, required high-altitude aircraft photography for identification. The 10 change areas not detected from the Landsat imagery include changes from forest and urban open to light crown cover forest and changes from nonforested wetlands (category 61) to a reservoir (category 53). The size of these areas appears not to be a factor in the difficulty of their detection. Interpretation of change in this fashion required 88 man-hours, of which approximately 32 were devoted to the interpretation and initial mapping process and the remainder to the preparation of graphics (Alexander, 1973).

One of the major concerns of CARETS investigators in using Landsat imagery was whether subsequent Landsat imagery would be of consistent color tone and resolution to make land use change analysis possible. Investigators compared the Level I land use as originally mapped from enlarged 1972 Landsat imagery with enlarged 1974 Landsat prints to identify and map areas of land use change. They compared the land use changes as identified to field data to determine if the differences on the imagery were due to actual changes in the land use or were merely the result of a change in spectral reflectance from the time of the original imaging.

Researchers used 1972 color composite transparencies enlarged to 1:250,000 scale for the original land use mapping. For the change detection experiment, they selected Landsat 1974 color composite prints at the same scale. In this way the two images from October 1972 and November 1974 could be compared visually for obvious land use changes.

In addition to comparing the overall images for differences that would indicate change, the researchers could compare the land use as mapped in 1972 with the more recent imagery. By overlaying the land use map and the 1974 image, they could make this comparison directly. To detect change from Landsat imagery, researchers employed the 1-percent sample of the Central Atlantic region used in the CARETS map accuracy determination study. This sample included 28 nonurban sites and 15 urban sites (see figures 24 and 25). This method of examining sample areas provided a random distribution of sites across the CARETS region and the small sample made possible the examination of each site in detail.

In the change detection procedure, interpreters overlaid the Level I land use maps of the CARETS area on the enlarged Landsat prints. Where the land use as mapped did not agree completely with the new base, the interpreter suspected a land use change and drew a polygon of change on a drafting film overlay, indicating both the previous and the present land use. The interpreter then visually inspected the 1972 image for those details that appeared as change on the 1974 image. If the land use signature on the 1974 image was not visible on the 1972 image, the interpreter mapped the signature as a change, and noted a general description of the type of change in the margin next to each change mapped.

Occasionally when a land use change was mapped, further comparison of the two enlarged images revealed that no true change had occurred. In the more recent image the land use feature was clear and easily identified. By comparing this view to the earlier image, the interpreter

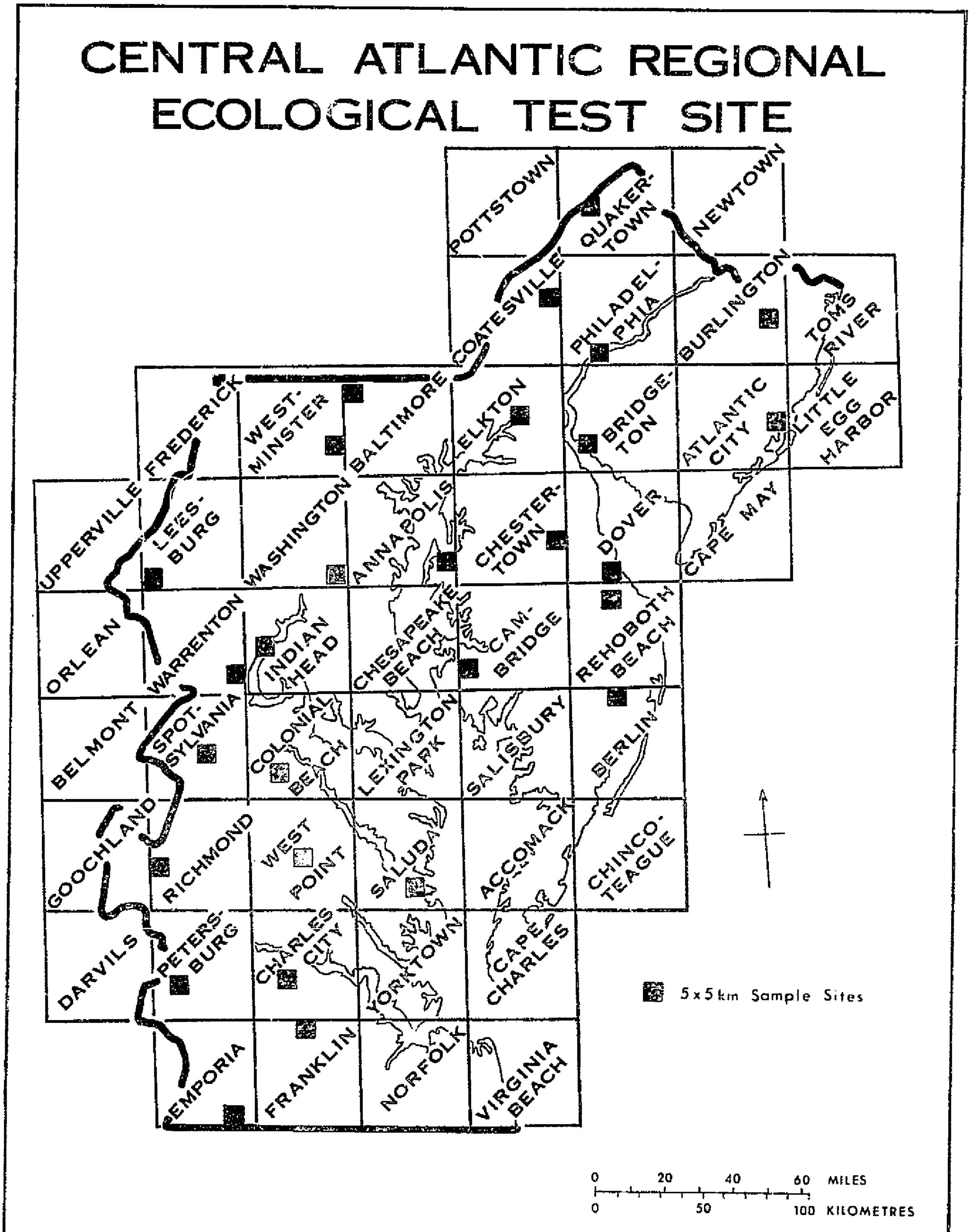



Figure 24 --Location of 5 X 5 km sample site within nonurban areas.

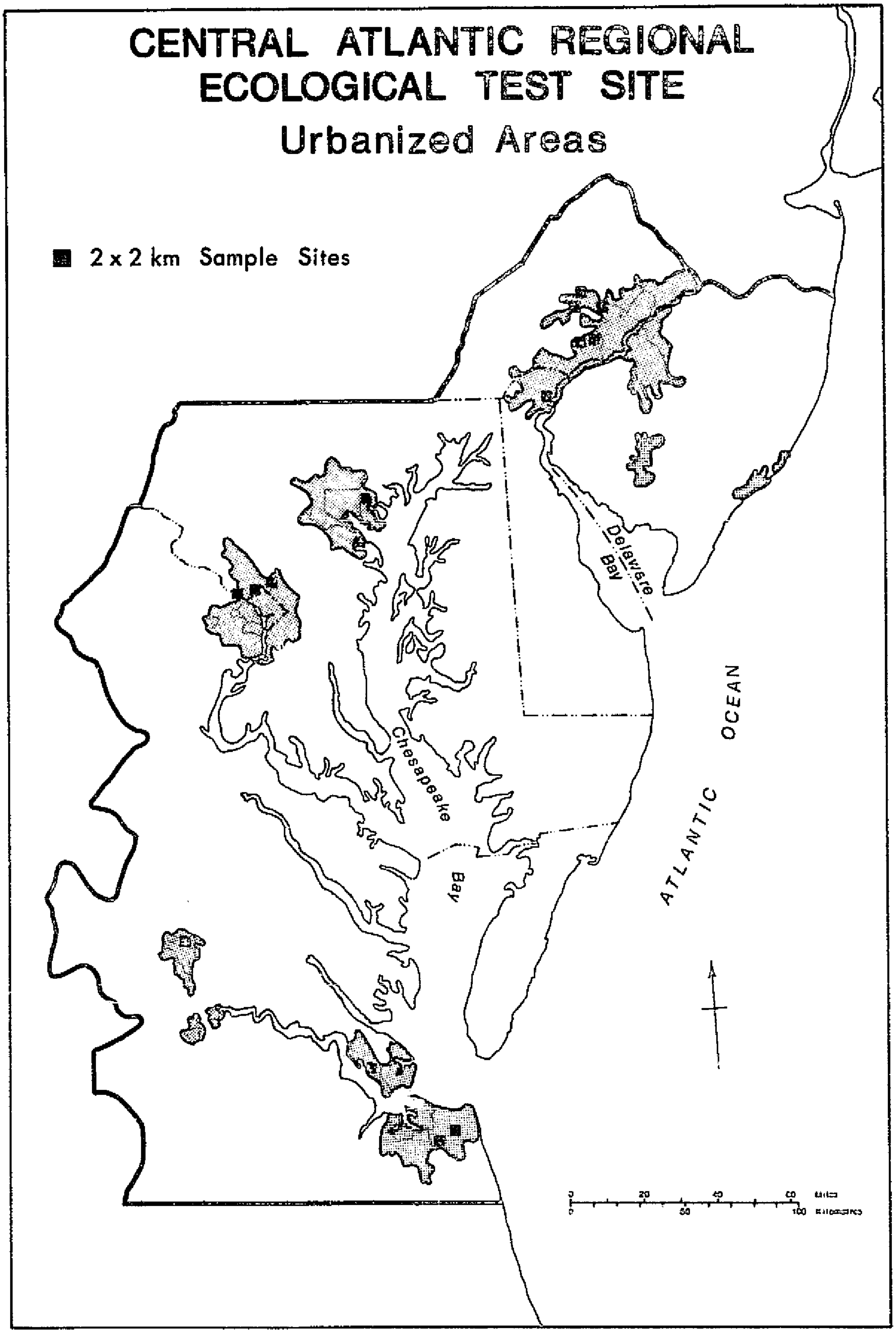



Figure 25 --Location of 2 X 2 km sample sites within urbanized areas. Shaded areas represent urbanized areas defined by the U.S. Bureau of Census, Census of Population: 1970 Vol. 1 & 2.

was able to identify the same land use feature previously overlooked and correct the misinterpretation on the 1972 map. Researchers verified questionable changes by referring to the notes obtained during the field work for the accuracy study.

Comparison of Landsat imagery over a 2-year period reveals certain inherent problems in observing change. Even when selecting two sets of imagery from the same month or season, the interpreter will find unavoidable variations in the reflectance from surface features. These variations are due to several influences, including the quality of the vegetation growth, the condition of the agricultural fields, the attenuation by the atmosphere, and the image processing techniques.

The color composite prints produced from the 1974 imagery had more color variation and less dominance of red than the color composites of 1972 imagery. This increased color diversity facilitated land use mapping. Certain land uses, such as verdant fields, were identifiable, whereas, in the more reddish image from 1972, the red signature of the fields appeared as forest. Another problem more easily resolved with the later imagery was urban land that had been previously difficult to distinguish from fields of dry grass. On the 1972 imagery the dry grass fields had a more blue-green color whereas urban areas appeared blue-gray.

Image variations from one year to the next resulted in the interpreter's detecting a land use change. Frequently, however, this change would have been more appropriately termed "correction" as it was actually a reinterpretation of the same ground conditions using improved data. Occasionally the identical small field or forest pattern appeared

C-2

to have increased in size during the 2-year period. On the 1972 imagery the land parcel appeared to be below the minimum mapping size; on the 1974 imagery, however, it appeared to be of a size large enough to map. When the field size was checked against the field data and the 1:24,000 scale topographic map, researchers found the size had remained the same. This apparent change in size resulted from the increased contrast between two land uses on the image, making the smaller pattern more visible.

Interpretation problems also resulted from land use observed to be the same on both 1972 and 1974 imagery yet differing in the placement of a boundary line. As in the case above, this discrepancy was often due to a difference in the contrast between the two land uses. Where the map boundary approximated that of the land use boundary on the recent image, interpreters made no change. If, on the other hand, the boundary was significantly different and, if redrawn would create a polygon larger than 4 $mm^2$, the interpreter mapped the newly formed polygon as a change.

All of these changes, if mapped, would result in an updated map. The assumption, however, that the change polygons all result from actual land use change is erroneous. Researchers examined the changes as mapped in the 28 nonurban and 15 urban sample sets to determine the cause of the land use change. Of 22 polygons and 3,228 ha of change mapped, only 5 polygons of true change occurred, comprising 316 ha in a total of 4 sites.

The true land use changes occurred on the Coatesville, Elkton, Rehoboth and the Washington sites. The changes occurring on the Coatesville site (see figure 26) are new housing developments, which were previously forest and farmland. The key here is the blue signature of urban land in an area previously mapped as either forest or agricultural. The imagery in 1972 for this area shows no sign of urban development. To the upper right just outside the sample site a reservoir showed up quite clearly in 1974 that was not present at all on the 1972 imagery.

At the Elkton site (figure 27) the land use change appears to be an agricultural field where forest previously stood. The 1974 image shows clearly a field pattern, whereas the land use map identifies this area as category 4, forest land. By comparing the imagery, one can see that the field, originally too small to map in 1972, has been increased in size by cutting into the forest. The total field is then mapped as a change from forest in 1972 to cropland and pasture in 1974.

On the Rehoboth site an area identified as agricultural land in 1972 appeared in 1974 to be aforesting (see figure 28). Researchers confirmed this situation during a field verification flight; the site was subsequently shown on the map as having changed from agricultural land to forest land.

In the Washington site, an area originally mapped as agriculture was found to be predominantly forest. Although the actual use was a mixture of residential land, cropland, and forest, using Landsat imagery interpreters could only distinguish the agriculture or forest categories. In 1974 the forest category predominated and the land use was mapped as a change from the agricultural land use identified in 1972 (figure 29).

COATESVILLE SITE

1972 land use map
and ERTS image.
Scale 1:250,000

1974 land use map
and ERTS image showing
land use change.

Figure 26--Land use change from agriculture (2) to urban (1) identified in the Coatesville sample site using ERTS imagery. EDC-010114.

ELKTON SITE

1972 land use map
and ERTS image.
Scale 1:250,000

1974 land use map
and ERTS image showing
land use change.

Figure 27--Land use change from forest (4) to agriculture (2) identified in the Elkton sample site using ERTS imagery. EDC-010115.

REHOBOTH SITE

1972 land use map
and ERTS image.
Scale 1:250,000

1974 land use map
and ERTS image showing
land use change.

Figure 28--Land use change from agriculture (2) to forest (4) identified in the Rehoboth sample site using ERTS imagery. EDC-010116.

WASHINGTON SITE

1972 land use map
and ERTS image.

Scale 1:250,000

1974 land use map
and ERTS image showing
increase in forested
area to the minimum
mapping size.

Figure 29--Land use change from agriculture (2) to forest (4) identified in the Washington sample site using ERTS imagery. EDC-010117.

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An example of an area in which an incorrectly mapped polygon was corrected is in the Richmond site (figure 30 ). On the 1972 imagery fields along the river had a bluish cast and appeared to be urban land. On 1974 imagery, the same area was less blue and was clearly distinguishable from the urban category. Interpreters therefore corrected the land use area from category 1 to category 2.

In the Atlantic City site (figure 31), interpreters redrew the boundary between forest and wetland. They had difficulty distinguishing between a forest signature, appearing red, and a wetland signature. As a result, they included wetlands within the forest category. On the 1974 imagery the forest was more easily distinguished from the wetland and the boundary was redrawn to include more land in the wetland category.

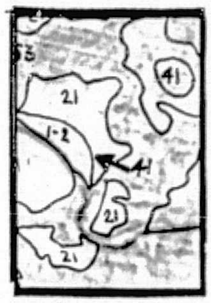
These land use changes and corrections are frequently close to the minimum mapping size and can easily be overlooked if a land use change analysis is conducted for the total area. Across large areas, these small changes would be difficult to notice. The amount of change during the 2-year period was insignificant, even for the small area sampled. Although one can identify changes in the imagery, one must validate each suspected change before mapping it.

For these reasons, Landsat imagery might best be utilized for monitoring land use changes at the regional level. For such studies, seasonal changes and short lived phenomena can be observed across a wider area. The use of sequential Landsat imagery will then provide an overview of a region with multiple land use types. Changes in the individual polygons of land use would not be as much of a concern as

RICHMOND SITE


1972 land use map
and ERTS image.

Scale 1:250,000




1974 land use map
and ERTS image showing land use corrections from urban (1)
to agriculture (2)

Figure 30 --Land use corrections from urban to agriculture in the Richmond sample site, mapped as a change from 1970-1972. EDC-010118.

ATLANTIC CITY

1972 land use map
and ERTS image.

Scale 1:250,000

1974 land use map
and ERTS image showing
boundary corrections
between forest (4)
and wetland (6).

Figure 31--Land use boundary change from 1970-1972, in the Atlantic City sample site, marked as a change from forest (4) to wetland (6). EDC-010119.

would the more general changes in land use patterns. Research into use of Landsat imagery for land use trends in a regional approach will be beneficial in future studies.

## COMPARISON OF LANDSAT AND AIRCRAFT DATA FOR LAND USE MAPPING

In discussing the value of Landsat imagery and high-altitude aircraft photography as sources of land use and land cover information, one must examine the remote sensor data from several points of view. Perhaps the most important viewpoint is that of the potential user. If remote sensor derived data have no applications, then attempts at extracting such data are wasted effort. Closely related are cost and accuracy factors. If the costs of acquiring data far outweigh any benefits derived from them or if the data's accuracy is so low as to make them useless, then again resources are not being well utilized in acquiring the data. Volumes 12 and 13 of the CARETS final report deal with user evaluation, and volume 6 concerns cost and accuracy aspects of the Landsat and aircraft data.

Closely related to user needs, accuracy and costs, however, are the advantages and disadvantages of using the different data sources from the interpreters' point of view and how these affect the important characteristics of the data.

Perhaps the greatest difference between Landsat and aircraft data results from the nature of the sensors--the scanner imagery versus a photographic system. An interpreter accustomed to recognizing features on aerial photography has considerably less opportunity to use such a skill in interpreting Landsat imagery. Although many features are identifiable on Landsat imagery (water bodies, airfields, highways), Landsat interpretation is more involved with recognition of spectral

signatures and patterns. Delimiting land use boundaries is one of the major tasks in land use mapping. The boundaries on Landsat imagery are often not well defined, although water and some forest boundaries are sharp. Partially as a result of the resolution problem, the accuracy of manually interpreted Landsat-derived land use maps is lower than that of maps derived from aircraft photography. The accuracy differential between Landsat and high-altitude aircraft photography is greater, the greater the level of detail desired. A Landsat-derived Level I land use map will be more accurate than such a map at Level II.

The resolution difference between Landsat imagery and high-altitude aircraft photography is significant. High-altitude aircraft photography can be enlarged many times without great loss in resolution, whereas the optical or photographic enlargement of Landsat imagery beyond the scale of 1:250,000 produces only more graininess and provides no aid to interpretaion.

Another major difference between Landsat imagery and high-altitude aircraft photography, which is closely related to the resolution issue, is the ease with which the photography can be used with the USGS land use classification system. The relative ease of identifying features on the photography makes such data easily adaptable to generalized classification schemes. The Landsat interpreter, on the other hand, has greater difficulty because certain spectral signatures appearing on Landsat imagery represent land use categories or mixtures of land use that are not accounted for by the USGS classification scheme. This phenomenon is most apparent in the urban-rural transitional zone,

whose varying land uses are numerous and mixed. Moreover, one using Landsat data manually or automatically finds that two or more different land uses have the same spectral signatures and that the same land use may have several different signatures. Also Landsat signatures change from season to season.

Landsat imagery does present some advantages to interpreters. Foremost of these is the aid that Landsat provides in generalizing land uses. CARETS researchers found that the time from mapping Level I land use from high-altitude aircraft photography was over 5 times that for mapping the same area using Landsat imagery at the same scale and level of detail. If a user needs a highly generalized land use map, interpreters can produce it quickly and inexpensively from Landsat imagery. Landsat imagery also allows for the use of four different bands, coverage from all seasons and false color composites.

From experiences with both high-altitude aircraft photography and Landsat imagery, CARETS interpreters conclude that the photography is most useful for obtaining Level II or higher detailed information, although using it requires greater time and expense. The lower resolution Landsat imagery cannot provide as highly detailed and accurate land use data as the aircraft photography, but for preparing highly generalized maps, one can use it easily and inexpensively. The basic problem with Landsat imagery is that its spectral signatures do not always coincide with categories in land use classification schemes. For rural land uses, the difference between Landsat imagery and high-altitude aircraft photography is considerably less than is the difference in urban areas.

## RECOMMENDATIONS

Interpreters involved in the compiling of CARETS data made several recommendations that would facilitate data compilation. Some of these suggestions are easy to adopt and have been adopted. Other suggestions, though helping the interpreter, would be more difficult or expensive to implement.

A major recommendation based on the CARETS experience is the adoption of the revised USGS land use classification (table 6). The CARETS interpretation and accuracy suffered because the compilation was conducted during the development of a land use classification scheme when both categories and definitions of categories were changing. The prototype scheme used by the CARETS project had several weaknesses that were eliminated in the drafting of the USGS Circular 671 classification scheme and the subsequent scheme to be published in Professional Paper 964. This revised scheme is more directed toward categories interpreters can detect consistently from remote sensor data than previous schemes.

The methods and materials used by CARETS interpreters in using high-altitude aerial photography should be changed to improve the land use maps. The quality of the photography is important, and interpreters should use as high a quality source photography as possible. The use of color infrared photomosaics rather than black and white photomosaics, though considerably more expensive, would also facilitate mapping. Interpreters should use microfiche viewers rather than monocular lenses for enlarging the film. Besides providing greater magnification, the microfiche viewer provides a larger field of view, and is easier on the

interpreter's eyes. For difficult-to-interpret parcels of land, especially in urban areas, a mirror stereoscope should be used. Larger scaled photography--either color or black and white--would also be helpful in identifying difficult-to-interpret land uses.

Working conditions and personnel often affect the quality of the final product. If possible, all work should be performed in an area free of constant disruptions. Untrained personnel should not be used to prepare cartographic or photographic products, and at least one competent person should be involved solely in editing or quality control. If compilation is being conducted by an outside contractor, the products should be rigorously edited before being accepted.

The compilation of land use and land cover data from Landsat imagery was an experiment in which interpreters developed several new techniques. Landsat color composite transparencies should be used for mapping rather than black and white imagery. The color imagery is so superior that it is well worth the additional cost. Landsat imagery should be interpreted only to Level I rather than to some Level II and Level III categories. Although using all three levels was valuable on an experimental basis for identifying the land uses visible on the imagery, the lack of consistency in levels of generalization is confusing to the user of the maps. Moreover, for a map as generalized as the Landsat derived land use map at a scale of 1:250 000, a few areas of greater detail contribute little to the value of the maps. In compiling land use data from Landsat imagery, one should use all available auxiliary source materials rather than the Landsat imagery alone. In the CARETS project, interpreters did not use other sources because they wished to test the value of the imagery by itself, but using other sources as interpretation aids would

improve the accuracy of the Landsat derived maps. Finally, Landsat imagery should not be used for change detection studies without correlative information. Although the imagery does facilitate identifying areas of change, many of the changes one identifies on the imagery are false and all areas must be verified by using high-altitude aircraft photography or other sources.

In both land use compilation and change detection studies CARETS interpreters had difficulty adhering to the minimum mapping size. Interpreters working on change detecting studies often detected areas that they believed had changed but rather had not been mapped originally because they had been judged beneath the minimum mapping size. To alleviate this problem and insure greater uniformity, interpreters should use a 2mm x 2mm template instead of relying on a hand lens scale to determine what areas are large enough to map.

A final recommendation concerns field checking to determine or improve map accuracy. CARETS researchers spent much time checking land use from the ground that could more effectively be examined from the air. For field checking, light aircraft should be used whenever possible to save time and to reach otherwise inaccessible areas.

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